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Effect of Liquid Hog Manure Application Rate, Season, and Method on Native Rangelands and Associated Tame Pastures in South-central Alberta

By

Laura Jean Blonski ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of *Master of Science in Rangeland and Wildlife Resources*

Department of *Agricultural, Food, and Nutritional Science*

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Vegetation Responses to Liquid Hog Manure Application on Native Rangeland and Tame Pasture in Central Alberta* submitted by *Laura Jean Blonski* in partial fulfillment of the requirements for the degree of *Master of Science in Rangeland and Wildlife Resources.*

Abstract

Research initiated in south central Alberta aims to document the response of four unique plant communities, two native and two seeded pastures to different rates (10, 20, 40, 80 and 160 kgNH_3-N.ha^{-1}), methods (dribble broadcast vs. sub-surface injection) and seasons (fall vs. spring) of liquid hog manure (LHM) application. This research was initiated in an effort to ascertain the feasibility of future widescale LHM application in this region; an area into which hog operations have recently expanded. Objectives of this research included assessing forage yield and quality, as well as plant community responses to LHM application. The latter objective is especially of interest on native rangelands, as these areas are typically managed as closed, self-sustaining entities. A secondary objective included comparison and contrast of relative responses between native and tame (e.g., seeded) plant communities.

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Chapter One

Introduction

1.1 Overview of Issue

The use of intensive management practices such as fertilization within agronomic systems have been widely accepted and implemented in western Canada. Such practices however, are far less prevalent on rangelands. This is partly a result of the pervasive philosophy that rangelands should be managed as "closed" or self-sustaining ecosystems, rather than areas subsidized with energy inputs such as fertilizers. It is also a function of the fact that most rangelands by definition occupy regions of the earth's surface lacking the favorable edaphic and climatic parameters prerequisite to the effective use of intensive agronomic practices (Holechek et al. 1995). For instance, much of the native prairie remaining in the province of Alberta is located in the south-east, a region that is semi-arid and has highly variable precipitation among successive growing seasons. Coupland (1959) suggests that the Northen Great Plains grasslands exist under recurring drought events, which vary in longevity and severity. These factors, coupled with less fertile soils, generally limit the growth of cultivated crops in the region. Another limitation associated with fertilization of rangeland systems, is the economic risk associated with fluctuating livestock and fertilizer costs (Godfrey et al. 1985).

Despite these edaphic and climatic limitations, the semi-arid areas of Alberta are important for beef cattle production with native rangelands, much of them publicly-owned, providing a great deal of the forage. Recently, an increasing number of commercial hog operations have become established within the same region in order to minimize conflict with urban municipalities and other land users over factors such as aesthetics and odor. A recent study found that nearly 30% of Alberta's hog production is occurring in south-central Alberta (Alberta Agricultural Statistics Branch 1997). While hog operations do not directly utilize the surrounding tame pasture and native rangeland, they do have a potential impact in terms of manure handling and processing. The transport of large volumes of hog manure long distances to annual cropland - the traditional sink for

animal manure, is clearly neither practical nor cost-effective. As a result, there is an urgent need for new sinks to be identified for hog waste disposal as the industry increases its size and scope, especially as quantities of manure become available in excess of crop requirement (Antoun et al. 1985).

Widely available tame pastures and native rangelands within this area could act as an alternative sink for manure produced by newly established hog operations. These plant communities have the capacity to respond positively to manure application, as evidenced in unmanaged plant-soil systems. More widespread applications of manure, coupled with appropriate land management strategies have the added potential to benefit plant growth and performance (West 1981). If forage lands in south-central Alberta could act as a sink for either surface or sub-surface applied liquid hog manure (LHM), this could allow the hog industry to sustainably expand the geographic extent of their operations within the province.

While the benefits of using fertilizers on cultivated crops have been extensively researched, less is known about the possible gains attainable through perennial forage fertilization, particularly on native rangelands. While some peer-reviewed literature has examined the effect of commercial fertilizers such as ammonium nitrate on prairie rangelands (Jacobsen at al. 1996; Read 1969), there has been even less research on the application of manure, especially in liquid form, to either native rangeland or tame pasture. Recent research initiatives in western Canada have begun to examine the impact of manure application, with the majority occurring either on cropland or tame pastureland. For example, Pastl et al. (2000) examined the response of crested wheatgrass, Russian wildrye and mixtures of smooth brome/alfalfa to sub-surface applied LHM. Earlier research has shown that both nutrient uptake and silage corn yield increased due to broadcast applications of LHM (Antoun et al. 1985). Overall, there is a surprising deficiency of information on native rangeland response to manure (or fertilizer) application. As a result, there is a need to quantify the responses of native rangelands and adjacent seeded pastures to different LHM application methodologies, and to contrast the responses of tame pastures and native rangelands where they co-exist.

The addition of nutrients, especially N and P, within LHM are likely to affect the quality and quantity of forage. On native rangelands, where intensive management is not the norm, there may be an increased risk of adverse compositional changes within the plant community. Such changes may be characterized either by a loss of desirable species, an invasion of unpalatable or weedy plants, or a combination of the two. LHM application may alter animal preference and use patterns, resulting in either enhanced or reduced levels of harvest efficiency by livestock (wildlife). Certain physical factors beyond human control (e.g., climate and soils) may also pose limits on the effectiveness of manure application, necessitating the need to identify such factors. Due to the unknowns related to LHM application on both native rangeland, and to a lesser degree, tame pasture, this research will be critical in establishing appropriate guidelines for LHM application, including rate, method (surface vs. sub-surface), and season (spring vs fall). At the end of this research, it will also be important to determine whether differences exist in the response among different forage types (native vs tame) within the same region. Such information is pivitol in revising management guidelines (e.g., existing 'Code of Practices for the Safe and Economic Handling of Animal Manures') for the application of LHM to either tame pasture or native rangeland.

Currently, manure application guidelines are limited in scope. The 'Code of Practice for the Safe and Economic Handling of Animal Manures' (1995) does set forth some direction in this regard. However, this document lacks detail and fails to address a broad cross-section of land types and ecological concerns. In Alberta, specific procedural information should address manure management on arid, semi-arid and sub-humid areas, and include native rangeland and tame pastures as well as agronomic crops. This information could assist in promoting the safe disposal of (hog) manure by the hog industry and facilitate its effective utilization by other interested groups (e.g., local area farmers). As such, more extensive guidelines are needed in order to ensure hog manure application is carried out in a manner that is both socially and environmentally sound, while still providing an economic benefit. This is especially true on public lands, where the pressure to retain biodiversity and ecosystem sustainability (e.g., ecological integrity) of native plant communities is considerable.

Given that current manure application guidelines are limited and that physical factors put a realm of uncertainty on LHM application initiatives, there is a need for current research on both native prairie rangelands of south-eastern Alberta and associated tame pastures. The effect of liquid hog manure application on both types of land-bases needs to be compared and contrasted. This thesis describes research conducted in the Mixed Grass region south-west of Hanna, Alberta, to evaluate the response of both native and tame vegetation to both spring and fall treatments of various LHM application rates, applied either to the soil surface, or injected directly into the soil matrix. Vegetation responses were monitored in order to identify the appropriate target rates of application and the proper timing and method of application, on both native rangeland and tame pasture within the region.

1.2 Specific Objectives of the Research

- To identify appropriate rates (10, 20, 40, 80, and 160 $kgNH_3\text{-}N.ha^{-1}$) of application of liquid hog manure onto both tame pasture and native rangeland so as to maximize increases in above-ground phytomass and forage quality (e.g., acid detergent fiber and crude protein), while minimizing adverse changes in botanical composition.
  - (a) H1: Increasing the application rate (10, 20, 40, 80 and 160 $kgNH_3\text{-}N.ha^{-1}$) of liquid hog manure will not alter phytomass yield, crude protein, and forage palatability.
  - (b) H2: Increasing the application rate of NH3 in liquid hog manure will not alter the cover of weedy undesirables and change sward botanical composition.
  - (c) H3: Changes in botanical composition, phytomass, CP, and forage palatability will not differ between tame and native sites.
- To identify response differences to the method of application (broadcast VS injected) of LHM and to assess whether one method is superior.
  - (a) H1: Effects of LHM application will be the same regardless of whether the manure is broadcast or injected into the soil matrix.

- To identify response differences to the season of application (fall VS spring) of LHM and to assess whether one season is superior.

  (a) H1: Effects of LHM application will be the same regardless of whether the manure is applied in the spring or fall.

- To evaluate differences in response to manure addition in both native rangelands and associated tame pastures.

  (a) H1: The response of tame pasture and native rangeland to nutrient addition will be the same.

- To enable pork producers to explore increased utilization of private and public areas for manure application where much of the local landbase is dominated by tame pasture and native rangeland, while simultaneously addressing public concerns regarding the environmental sustainability of LHM application.

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Chapter Two

Literature Review

2.1 Introduction

Treating vegetation with nutrient additions to boost overall plant performance and yield is not a new phenomenon and is a basis of agriculture worldwide. In developed countries, the use of commercial fertilizers to assist plant growth and enhance yields is common. Commercial fertilizers typically contain a mixture of the macronutrients: nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Of these, the nutrient most frequently constraining plant growth and development is N (Wight and Black 1979; Power 1972), necessitating its need for application as either urea or an ammonium compound.

Application of commercial fertilizer has been done using several methods. Perhaps the most common and least expensive being surface broadcast where fertilizer is spread or sprayed onto the landbase. However, such applications have been criticized because they often lead to drift, atomization, and volatilization (Hoff et al. 1981). Furthermore, the effectiveness of broadcast treatments is highly correlated to weather: dry, windy conditions increase nutrient losses due to drift and volatilization, leading to relatively ineffective capture and use of applied fertilizer (Bittman et al. 1999). Alternatively, cool and calm conditions minimize atmospheric losses. Since variability in response is linked to ambient weather, it is difficult for land managers to manage broadcast fertilizer applications to achieve consistent, reliable vegetation responses.

Though broadcast fertilizer applications are still common, other options exist to apply fertilizer with a greater year-to-year consistency. Fertilizers can be broadcast onto the soil surface and incorporated into the soil matrix via cultivation. Alternatively, fertilizers can be placed directly into the soil using specialized equipment (Pastl et al. 2000; AFMRC 1999). Although both methods reduce gaseous nutrient losses and improve the consistency of crop response, the associated economic and energy costs are high. An alternative is the use of slow-release capsules, where

fertilizer is coated in an inert substance and then placed in the sub-soil, resulting in the gradual release of fertilizer over time to the benefit of the crop. However, this technology comes at a price beyond sheer product (e.g., fertilizer) cost. New technology and non-conventional approaches to land management often require specialized equipment, training and labor, factors that may limit the effectiveness of technology transfer from industry to land manager or rancher, and ultimately deter widespread adoption of new techniques.

As a result, alternative nutrient sources including animal waste are beginning to be employed on a greater scale (Pastl et al. 2000). Within unmanaged plant-soil systems, manure plays an important ecological role and benefits plant growth. More widespread application of manure could improve plant growth and performance, while reducing economic costs (West 1981).

Unfortunately, public perception of land application of manure is a formidable obstacle to livestock industries within Alberta and across North America. Potential problems include odor, soil and/or plant community degradation, and a risk of declining water quality. Fortunately, proper management of manure can effectively ameliorate most problems. Odor can be reduced by applying manure on calm days, or by incorporating manure directly into the soil. A comparison of broadcast and surface-banded (sleigh-foot) application of liquid dairy manure in British Columbia showed lower ammonia losses and a more consistent crop response when manure was surface-banded (Bittman et al. 1999). Liquid hog manure applications within Alberta have examined pulse-bander (AARI 1992) and injection (AFMRC 1999) technology, both of which allow for sub-soil manure placement.

Extensive research is needed to delineate how, where, and when, manure application is socially acceptable and environmentally responsible, particularly if the goal is to simultaneously promote plant growth and enhance forage yield. This is needed in order to promote the beneficial but safe use of this valuable resource by farmers and land managers. Manure application procedures and guidelines also need to be concisely written in a user-friendly manner to ensure effective technology transfer and use by practitioners.

Although the swine industry generates great quantities of liquid manure (AAFRD 2000), this resource is more than 90% moisture and is adaptable to mechanical handling (e.g., storage, agitation and application/disposal) (West 1981). Specific procedures for the land application of manure are needed. For Alberta, these procedures should address manure management on arid, semi-arid, and sub-humid areas, and include native rangeland and tame pastures as well as agronomic crops. Such information could assist in promoting the safe disposal of manure by the hog industry and effective utilization by other interested parties (e.g., local ranchers).

2.2 The Hog Industry in Alberta

Alberta currently contributes ~ 15% of Canada's total hog production (AAFRD 2000). Hog production within the province, as censused on July 1st 1995, was estimated to be at 2,017,000 animals (Alberta Agriculture Statistics Branch 1997). Of this, more than 28% were produced in south central Alberta (Alberta Agriculture Statistics Branch 1997) representative of the Drumheller, Wainwright and Camrose census areas, respectively. It is worthwhile to note that Alberta's contribution to national hog production has decreased by ~ 10% since the mid-1950s (AAFRD 2000). This decline is significant, but plenty of opportunities remain for future expansion of Alberta's hog industry. Although pork is the most widely consumed meat globally, it is not widely traded on this scale (Church 1997). Thus, in a global context, there is great opportunity for Alberta to become a dominant player in the export of pork and pork products, but would require the industry to expand, as well as make key changes in the relationships between production and marketing.

Even without further expansion of the hog industry within Alberta, there are still social and environmental concerns regarding the storage and disposal of manure. Public concerns include odor and ground-water contamination, with lesser concerns including pest management (e.g., flies) and adverse affects on the landbase (e.g., vegetation damage or weed spread, for example). The 'Code of Practice for the Safe and Economic Handling of Animal Manures' (1995) sets forth some direction

regarding such concerns. However, this document is limited in scope. Furthermore, this document does not cover the breadth of land types either currently used or under consideration for manure application within Alberta. More detailed guidelines are needed to safely direct hog manure application in either solid or liquid form. With the increasing cost of commercial fertilizer, it seems intuitive to apply manure in an effort to assist plant growth at a reduced economic cost (West 1981). As such, hog production operators should be encouraged to capitalize on this resource, so long as its use is environmentally and socially responsible.

2.3 Plant Community Ecology

2.3.1 Rangeland Ecology

Ecology is the science of relationships among and between both biotic and abiotic components of an ecosystem. In ecology, there are functional relationships between various components, which lead to interdependency amongst the various elements (Holochek et al. 1995). Therefore, a change in one part of the system may elicit responses in others. For example, a change in climate (abiotic) influences primary production (biotic), which in turn influences primary, secondary, and tertiary consumers. Relationships among the many biotic and abiotic factors are complex and diverse in their nature and response patterns. When ecological principles are applied to rangelands, it becomes an applied rather than a basic science, as we attempt to manipulate the ecosystem to our individual or collective benefit. This benefit may provide sufficient, high quality forage for livestock (and wildlife), or simply maintain a diverse, weed-free native plant community.

2.3.2. Mixed Prairie Grassland

In Alberta, the Mixed Prairie and Fescue Grasslands are the northern-most extension of the Northern Great Plains (Coupland 1950). Mixed Prairie is generally more xeric in nature and has evolved with the influence of fire, grazing, and drought. Biomass production is largely constrained

by water availability and soil nutrient status (Willms and Jefferson 1993). Mixed Prairie vegetation typically includes both mid (e.g., *Stipa* & *Agropyron* spp.) and short-grasses (e.g., *Bouteloua gracilis* (HBK) Lag.) (Coupland 1992a). Presumably, the co-existence of these two types evolved over time in response to variability of precipitation. The specific mix of dominant species is dependant on regional moisture regime, and consequently determines the production potential of the community. Rough fescue occurs as a co-dominant along the northern-most fringe of the dark brown soil zone, where moisture availability is more favorable (Coupland 1961). Moss and Campbell (1947) found that there is a 'natural tension zone' between *Festuca* and *Stipa* dominated communities, resulting in inter-mixing of these two associations within this zone.

The *Stipa-Agropyron* range type (RT) examined in this study represents a more mesic faciation within the Mixed Prairie, relative to the *Stipa-Bouteloua-Agropyron* or *Stipa-Bouteloua* faciations (Coupland 1961). The former RT is found on well-developed soils in the dark brown zone and occupies more xeric areas relative to Fescue Grassland (see section 2.3.3). Typical dominants include a combination of *Stipa curtiseta* (A.S. Hitchc.), *Stipa comata* Trin. & Rupr., *Agropyron smithii* Rydb. and *Agropyron dasystachym* (Hook.) Scribn. Coupland (1961) indicates that there is a competitive ecological relationship between the *Stipa* species, with moister situations favoring *S. curtiseta* over *S. comata*; however, the relative ecological ranking between the aforementioned *Agropyron* species is unclear.

2.3.3. Fescue Grassland

Of Alberta's 6.5 million hectares of native prairie, Fescue Grasslands comprise ~ 13% (Dormaar and Willms 1990), with the majority occurring in the Fescue Prairie foothills of south-western Alberta. Fescue Grasslands can also be found, however, north of the Mixed Prairie, within the Aspen Parkland ecoregion (Coupland 1992b). Dominant graminoid communities within these Fescue Grasslands vary depending upon regional location, climate, soils, and disturbance history (e.g., fire, grazing, etc.). Within the foothills, Fescue Grassland occupies rich black chernozemic soils and is dominated by foothills rough fescue (*Festuca campestris* Rydb.) (Dormaar and Willms 1990). Fescue

Grasslands occurring in association with the Aspen Parkland are dominated by plains rough fescue (*Festuca hallii* (Vasey) Piper), a shorter statured species with rhizomes ending in a dense mat (Pavlick and Looman 1984). When this grassland is found in association with Aspen Parkland, the plant community is representative of a transition from forest to more xeric Mixed Prairie (see section 2.3.2).

While *F. hallii* can dominate sites under favorable moisture conditions, it can also occur together with other species (Coupland and Brayshaw 1953). At the northern edge of the dark brown soil zone, F. hallii co-dominates with *Stipa curtiseta*, a common grass of the northern Mixed Prairie (Coupland and Brayshaw 1953). Where this occurs, the plant community is grouped and described as a *Festuca-Stipa* RT.

2.3.4 Tame Pasture Ecology

Tame pastures typically consist of a relatively low number of species seeded together onto a landbase. Seeded species are generally introduced cultivars; selected and bred for their agronomic (e.g., yield) potential. Though less diverse than adjacent native rangelands, tame pastures play an important role in livestock production as they supply hay reserves, and are often critical for early season grazing, a time when native species are more susceptible to damage from grazing. Within the context of this chapter, discussion will be limited to three key forage species found within the study sites.

2.3.4.1 Alfalfa

Alfalfa (*Medicago sativa* L.) is a perennial, leguminous forb, and is the mainstay of many Alberta pastures. This forage plant has the distinction of being cultivated before recorded history, and, there is general agreement that its origin was likely Iran (Barnes and Sheaffer 1995). Alfalfa is currently worldwide in its distribution. Alfalfa is quite hardy, withstanding a wide temperature range and is relatively tolerant of drought (Barnes and Sheaffer 1995). Alfalfa has the capacity to

biologically fix N, reducing its reliance on N inputs relative to grasses and other non-leguminous plants. Though rates of biological N fixation in legumes are difficult to quantify, in large part due to the breadth of species/cultivars and growing conditions involved, West (1975) estimated that annual N fixation rates in the western USA are likely in the order of $16kg.ha^{-1}$.

Research has shown that alfalfa does not necessarily respond well to nutrient addition. Alfalfa yield has been shown to decline with an increasing rate of N application (Bittman et al. 1997; Russelle 1992; Lutwick and Smith 1977). In mixed pasture stands, legume populations are prone to decline in response to N application due to increased competition from the non-leguminous (e.g., graminoid) component (Russelle 1992).

2.3.4.2 Crested Wheatgrass

Crested wheatgrass (*Agropyron cristatum* L.) is a hardy forage grass, introduced into North America in the late 1800s from Russia (Holochek 1981). It was not until the 1930s that this grass came into prominence (Lorenz 1986). During the 'dust-bowl' era, crested wheatgrass was planted extensively across the prairies in an effort to provide vegetative cover, stabilize soil and reduce erosion (DeLuca and Lessica 1996; Lorenz 1986). Since then, this species has become a well-known forage grass and is the most commonly planted exotic grass in North America (DeLuca and Lessica 1996).

In western Canada alone, it is estimated that crested wheatgrass occupies over one million hectares (Dormaar et al. 1995). Part of its widespread use is likely due to three significant factors. First, crested wheatgrass is well suited to a variety of soils, including those with either a high proportion of clay or sand (Knowles and Buglass 1980). Second, crested wheatgrass is highly drought tolerant (Johnson 1986). Third, this grass is forgiving meaning it is able to thrive despite poor management (e.g., heavy grazing) or sub-optimal site conditions (Sharp 1986), potentially due in part, to the extensive root system of this species (Walton 1983).

In terms of pasture performance, crested wheatgrass is often more productive than adjacent native rangelands (DeLuca and Lessica 1996; Redente et al. 1989). Established swards of crested wheatgrass are known for their ability to incur rapid, early season growth, providing abundant forage during the early part of the growing season (Walton 1983). Furthermore, crested wheatgrass exhibits high forage quality early in the growing season (Walton 1983; Johnson 1986), with crude protein reaching levels as high as 20% (Malechek 1986). Crested wheatgrass is often preferred over native range by livestock in the spring (Smoliak 1968), and has led to greater weight gains. Swards of crested wheatgrass are often long-lived, and it is not unusual to find stands that are 40 or 50 years old (Holochek 1981). Furthermore, Crested wheatgrass responds well to fertilization (McCaughey and Simons 1999; McCaughey and Simons 1996; Lutwick and Smith 1977; Black 1968), with yield increasing with rate of N application. Black (1968) found that crested wheatgrass yields were greatest in the year of N application. This contrasted with native grasslands, which generated greater residual (e.g., second year) yield responses following poor initial yield increases.

Despite the positive attributes of this forage species it is critical for land managers to recognize its potential disadvantages. DeLuca and Lessica (1996) warn that the highly competitive nature of crested wheatgrass makes re-colonization by native plant species almost impossible. Thus, plantings of crested wheatgrass may be less than desirable where the long-term goals include re-establishment of native prairie vegetation (Johnson 1986). Furthermore, crested wheatgrass swards may differ significantly in below-ground properties relative to native prairie ecosystems. Wilson and Christianson (1999) demonstrated that early spring root mass and root:shoot ratios were significantly lower in crested wheatgrass pastures than on native prairie rangeland. In contrast, native rangelands have relatively greater root mass, which translated to increased energy flow through the soil-plant continuum. Related research has shown that crested whatgrass has less root mass per unit area relative to adjacent native grassland communities (Dormaar and Smoliak 1985). These tame stands also exhibit lower levels of soil carbon and nitrogen (Wilson and Christianson 1999), likely an artifact of reduced root growth and turnover.

2.3.4.3 Meadow Brome

Bromegrasses are an important forage resource on which the Alberta cattle industry depends (AARI 1994). Bromes are grown for hay or pasture as either a pure stand or as a component of a basic mixture. Smooth brome (*Bromus inermis* L.) is perhaps the best-known bromegrass, although, other related species are gaining in popularity. Meadow bromegrass (*Bromus biebersteinii* Roem and Shult.) is a shorter-statured bunchgrass, with high regrowth potential (Knowles et al. 1993). Originally native to southeastern Europe, this forage species was introduced relatively recently to North America (Knowles et al. 1993). Under pasture conditions, meadow brome produces dry matter more evenly through the season relative to smooth brome (Agriculture Canada 1986). This is likely an artifact of meadow brome's ability to initiate rapid regrowth following defoliation. Additionally, meadow brome responds well to fertilizer, and can be combined with frequent defoliation in pasture management. Research by Knowles et al. (1993) indicated four defoliations combined with annual fertilization of N (90 $kg.ha^{-1}$) and P (22 $kg.ha^{-1}$) led to annual dry matter yields for meadow brome greater than thoseof the other five forage species tested, including smooth brome and crested wheatgrass.

2.4 Plant Community Response to Nutrient Application

2.4.1 Exogenous Factors Influencing Plant Response to Nutrients

Above-ground production from perennial foragelands is correlated with numerous factors, some of which are beyond the control of management. These factors include precipitation, soil water, history of past use and resultant range condition, macro- and micro-nutrient status, as well as the genetic limitations of site-specific flora. Because the production potential of perennial grasslands is so dependent on exogenous factors, the exact effects of fertilization are variable and likewise correlated to these elements. In semi-arid regions, the most influential factor driving (or limiting)

production is plant-available water. Smoliak (1986) looked at climatic influences on forage yield over a 50-year period in Dry Mixed Prairie and found that forage production was highly correlated to previous year's precipitation. Additionally, previous fall precipitation influenced forage production. However, the best correlation was that of June and July precipitation coupled with May and June temperatures, which accounted for 63% of the variation in annual range productivity (Smoliak 1986). Johnson et al. (1969) found that yield response of both Mixed Prairie and Fescue Grassland vegetation was influenced primarily by fall soil moisture; however, spring (e.g., May-June) precipitation was also important.

Although nitrogen (N) limits production, its importance is second to moisture in arid regions such as the Prairie (Guevara et al. 2000; Willms and Jefferson 1993; Campbell et al. 1986; Lorenz and Rogler 1972). Even in the absence of adequate moisture, there are potential benefits from nutrient addition. For example, the addition of LHM to semi-arid rangelands and associated tame pastures may benefit the community directly by the addition of water, and by indirectly improving vegetation water-use efficiency (WUE). WUE is defined as the mass of dry matter produced per unit of water within a known area (Barker et al. 1989). Earlier research has substantiated that application of commercial N fertilizers to cool-season grasses increases WUE 3-fold to 13-23 kg/mm/ha (Power 1985). In comparison, unfertilized areas had more conservative WUE values of 3-9 kg/mm/ha (Power 1985). This confirms earlier research that showed grass WUE within the northern Great Plains increased with N application (White and Brown 1972). Increased WUE may be an artifact of enhanced root proliferation following N fertilization, a trait that allows plants to capture and extract moisture to a greater soil depth (Lorenz and Rogler 1957).

Beyond moisture constraints, initial nutrient status of the area may impact the effectiveness of nutrient addition. Adding nutrients to fertile sites would generate less gain in fertility and production relative to sites lacking nutrients. The history of range use is also important, and should be considered. Rangelands in excellent condition will respond differently than over-grazed areas, as plants with poor vigor have reduced root and photosynthetic capacity (Johnston 1961) and thus, are

less able to respond rapidly to nutrients. However, the response of moderately degraded rangeland may also be more pronounced than that of pristine sites, because those in excellent condition are already producing near capacity (Lorenz and Rogler 1957).

2.4.2 Above-ground Net Primary Production

Various research has demonstrated that forage productivity changes in response to nutrient addition are generally favorable (Jacobsen et al. 1996; Ukrainetz et al. 1988; Power 1986; Black 1968). Although there is some debate over what magnitude of N and P application are most beneficial to vegetation response, N is the most common nutrient constraint to plant growth and yield (Humphreys 1997). Consequently, vegetation response to P addition occurs only when N is not limiting (Black and Wight 1979). Similarly, other research illustrated that adding either N or N+P increased forage yield more than when only P was added (Johnston et al. 1967).

Though vegetation growth and production with nutrient addition has proven favorable, there exists great variability in yield responses on both temporal and spatial scales. Much of this variation is likely due to site-specific factors, including moisture and associated growing conditions. Some plant species or assemblages may better capture and utilize nutrients relative to other plant communities. Some of this differential response may be genetic, as there is significant interspecific variation in growth potential, yield response, and other forage characteristics following N addition (Jacobsen et al. 1996). For example, yield response to N in pasture often favors the graminoid component, to the detriment of legumes (Bittman et al. 1997; Dougherty and Rhykerd 1985). Similarly, rhizomatous, cool-season grasses (e.g., *Agropyron smithii*) have responded positively to either early spring or late fall nutrient applications relative to short-statured, warm-season grasses (e.g., *Bouteloua gracilis*) on both Mixed Grass and Short Grass rangelands (Samuel and Hart 1998; Rauzi 1978).

Differences in forage yield response to N fertilization also exist between tame (introduced) pastures and native rangeland communities. Tame pastures produce more dry matter yield relative to

native ranges in response to N additions (Johnston et al. 1968a). The pronounced response of tame forage is likely due to the fact that such species were selected for high yield response. Tame grass species are bred to be productive and adaptable to a wide range of site conditions and management practices (Looman and Kilcher 1983). The vast majority of native grass species are not as aggressive or competitive as the actively bred and selected cultivars of domesticated species (Looman and Kilcher 1983). Among native species, fire and weather history may also influence the response of vegetation, as do the type and origin of flora (e.g., arctotertiary (C3) vs. neotropical tertiary (C4)).

Annual weeds and/or undesirable plants can also be responsible for large increases in herbage yield following nutrient addition. An Oklahoma study found that yield increases from fertilization could be attributed to increases in native annual weeds including black-eyed Susan (*Rudbeckia hirta* L.) and broomweed (*Gutierrezia sarothrae* (Pursh) Britt & Rusby), rather than increases in either native grasses or legumes (Huffine and Elder 1960). Similar research within the northern Great Plains showed that increased yields were largely due to the growth of native annual and browse species, rather than desirable perennial grasses (Alsayegh et al. 1967). The explanation for these results may lie in the fact that weed species, particularly those that are short-lived, are often more adept at responding quickly to nutrient addition relative to long-lived grasses. This opportunistic response is genetically predisposed for annual plant species, as they need to establish and propagate quickly. Although weedy species have the ability to capitalize on nutrient addition, a heavy cover of desired vegetation (e.g., forage crop) and associated competition for light could limit weed establishment, even in high fertility environments (Pysek and Leps 1991).

Plant community responses to nutrient addition can also be examined from a temporal perspective, by looking at both short-term (immediate) yield responses, and longer-term (residual) responses. Although short-term above-ground net primary production (ANPP) response to nutrient addition can be dramatic, considerable evidence suggests that residual effects are just as important, and can last for several years (Jacobsen et al. 1996; Black and Wight 1979; Read 1969; Johnston et al. 1968a). Read (1969) found that residual native rangeland responses to fertilizer in southwestern

Saskatchewan were frequently greater than the first year effect. Similarly, Berg (1995) examined the residual yield response of native warm-season flora and found it was directly proportional to the amount of N applied, with herbage increasing 10 kg for each kg of N applied over the previous three years. These results contrast those of Godfrey and Wight (1985), whose research found forage yield was generally more pronounced in the first year following nutrient application, possibly due to immediate root stimulation and enhanced WUE. There are also likely to be differences in temporal yield responses among different plant communities. Black (1968) found swards of crested wheatgrass generated the greatest yield response in the year of nutrient application, while native grasslands showed the greatest yield response in the second year after treatment.

Poor yield response following N fertilization may be due to a lack of available moisture. Lorenz and Rogler (1973) stress that forage yields with different levels of fertilizer application are directly related to rainfall. Evidence from White (1985) showed that a lack of precipitation for one month after fertilization limited the response of western wheatgrass (*Agropyron smithii*) to N fertilization in the first year and may have caused some loss of the surface applied ammonium nitrate through volatilization. More recent research also indicates that the application of fertilizer N in dry years may not increase forage yield (Jacobsen et al. 1996), although it has been postulated that in such years, the added N remains in the root system as organic N to be used in subsequent years following root death and decomposition. Black and Wight (1979) suggest that the below-ground root system has the ability to act as a nutrient deficient sink, immobilizing large amounts of fertilizer, particularly N + P. Other research suggests that N may be subject to positional unavailability in dry years, particularly when N is surface broadcast onto a site (Jacobsen et al. 1996).

There is little information directly comparing different nutrient application methodologieson forage lands. Bittman et al. (1999) directly compared surface broadcast and surface banded applications of liquid dairy manure and found the latter reduced ammonia loss resulting in better capture and use of applied nutrients. Surface banded treatments required lower application rates relative to surface broadcast applications to achieve the same yield response (Bittman et al. 1999).

Olson and Papworth (1999) found that both dryland timothy grass and irrigated alfalfa yield in southern Alberta were not affected by method of manure application (injection vs. broadcast). No studies, however, have examined the application of nutrients to native rangelands using sub-surface application techniques.

The timing of nutrient application has been relatively extensively examined. Spring application of nutrients is a widely accepted practice. Spring applications that are executed prior to active (e.g., photosynthetic) growth assist plant growth and development. Furthermore, spring applications have been shown to benefit cool-season species because these plants commence active growth in the spring and are well-equipped to capture and use spring-applied nutrients (Wight and Black 1979; Rogler and Lorenz 1974). Campbell et al. (1986) found that forage yield response was greatest when nutrients were applied in either mid-April or late October/early Novermber. The same research suggested that nutrient application onto frozen, snow-covered soil reduced the efficiency of N use, resulting in lower forage yields (Campbell et al. 1986).

2.4.3 Plant Community Response

Although there exists a relationship between nutrient supply and plant community composition, the exact dynamics of this relationship are unclear. McMurphy and Nichols (1969) suggested that N fertilizer application could accelerate changes in botanical composition and aid in improving overall range condition. One thing is clear, that N fertilization can change the relative proportions of various plant species and/or functional groups (e.g., Samuel and Hart 1998; Bittman et al. 1997; Kalmbacher and Martin 1996). Research has demonstrated, for example, that the use of N fertilizer will increase grass production at the expense of legumes (and forbs) (Bittman et al. 1997; Russelle 1992; Dougherty and Rhykerd 1985; Lutwick and Smith 1977). Lutwick and Smith (1977) found that the proportion of alfalfa in the sward decreased with the onset of senescence and with the amount of N applied. Other literature has found that large applications of phosphorus (P) may increase alfalfa (forb) growth and abundance (Miller and Reetz Jr. 1995).

Over the last couple of decades, there has been mounting evidence that nutrient supply can exert control over the occurrence of specific plant species within a community. Evidence suggests that community diversity tends to decline along a nutrient gradient, with fewer plant species present on nutrient-rich sites relative to those with more moderate to poor nutrient conditions (Wilson and Tilman 1993, 1991; Wilson and Shay 1990). For example, plant diversity declined with increasing N application in Florida flatwoods range (Kalmbacher and Martin 1996). The relationship between community diversity and level of nutrient (N) application is important and requires attention, as the reduction or loss of species is often undesirable (West 1993), particularly on public lands. Though remote, there is a chance that very high levels of nutrient application may be a causative factor in plant death by burning vegetative tissue. Eradication of species from a plant community may also provide a potential niche for undesirable, invader species (Johnston et al. 1968b).

The invasion of weedy and/or unpalatable species following N fertilization is a real risk that has been well-documented. Research within south-eastern Alberta has found that high levels of N or N+P application on native rangelands precipitated the growth of undesirable, invasive plant species including *Hordeum jubatum* L. and *Descurrania sophia* (L.) Webb (Johnston et al. 1967). Likewise, Huffine and Elder (1960) showed that the application of commercial fertilizers to native rangeland within Oklahoma generated a 2-5-fold increase (by weight) in weed abundance. Certain unpalatable, native species may also increase in abundance following nutrient addition(s). *Artemisia frigida* Willd., an unpalatable half-shrub, has been found to increase in density following nutrient addition (Goetz 1969). Rangeland deterioration, characterized by undesirable changes in botanical composition, may be caused by repeated annual fertilization.

More subtle shifts in plant community composition may also occur following N fertilization. Some research on native rangeland has shown that the abundance of one species may increase with nutrient addition, generating simultaneous decreases in other species. Notably, research has found that nitrogen application increases the proportion of western wheatgrass (*Agropyron smithii*) at the expense of short-statured species such as blue grama (*Bouteloua gracilis*) and sedge (*Carex* spp.) (Samuel

and Hart 1998; Rauzi 1978). This result may reflect the ability of rhizomatous C3 grasses to better capture applied N, or their ability to vegetatively overtop and suppress the latter.

Black and Wight (1979) found that C3 species respond well to N fertilization. It has also been suggested that cool-season (e.g., C3) grasses initiate growth early in the spring, thereby rapidly utilizing the extra N and depleting valuable soil moisture reserves that warm-season (e.g., C4) grasses depend on later in the season (Samuel and Hart 1998). One study that examined the response of Mixed Prairie rangeland to N fertilization found that junegrass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.), a desired bunchgrass was reduced to near elimination at all rates of N application ranging from 224 to 672 kg.ha^{-1} (Houston and Hyder 1975), while other species, notably pasture sage and western wheatgrass, increased in abundance. Houston and Hyder (1975) also found that showy peavine (*Lathyrus polymorphus* Nutt.) was essentially eliminated at high N application rates. This finding is consistent with other research on tame pastures, that has shown introduced legumes (e.g., alfalfa) respond poorly to N addition, as they are out-competed by grasses. Other species, including Parry's oat grass (*Danthonia parryii* Scribn.) may be at risk of elimination from the sward at high rates of N (Johnson et al. 1968b).

2.4.4 Forage Quality and Chemical Constituents

Although a plant's nutrient potential is largely genetically predisposed (Monson 1981), the actual nutrient status reflects the integration of various factors including biological, edaphic and climatic considerations (Ellis and Foth 1984). Commercial fertilizer application has enhanced the forage quality of both native rangelands and tame pasture swards (Power 1986; Lutwick and Smith 1977). Power (1986) found that the average total N concentration of seven cool-season perennial grasses increased with 225 kg.ha^{-1} N, but not with lower application rates (e.g., 45 kg.ha^{-1}). This suggests that there may be a threshold application rate that governs quality response. Monson (1981) documented that crude protein (CP) increased as N fertilization increased. On tame pastures,

application of N to a mix of western wheatgrass and alfalfa yielded forage with increased yield and greater protein (Lutwick and Smith 1977).

As CP is one of the most important factors determining livestock health and production, there is considerable interest in maintaining sufficient CP levels to support livestock. One concern of fertilization is the potential to reduce the leguminous portion of swards (Bittman et al. 1997; Russelle 1992; Dougherty and Rhykerd 1985). Legumes and forbs are known to have high CP values relative to grasses throughout the growing season, and are therefore an important livestock forage source (Clarke and Tisdale 1945). Consequently, the benefit of N application to overall plant community forage quality must be weighed against any loss of the high-quality leguminous fraction in order to determine net changes in forage quality.

A further concern is that high levels of N may induce toxicity (Johnston et al. 1968b). High levels of fertilization may induce a toxic response in livestock, particularly in the first year (Johnston et al. 1968b). Halvorson and White (1980) indicated that excess N application to forages in Montana can precipitate nitrate build-up, to levels toxic for ruminants. This research also showed that *Stipa viridula* Trin. contained toxic levels of nitrates in floral tillers after being fertilized with 640 $kg.ha^{-1}$ of N. Nitrate poisoning can, however, occur at lower application rates of N.

Though forage quality can be manipulated through nutrient additions, there are other factors that affect plant forage quality. One of the major factors affecting plant nutrient status is phenology and the onset of senescence. If senescence is delayed, vegetation will retain a higher nutritive value over a longer period of time. Beaty and Engel (1980) found that as the season advanced, the ratio of dead to green components increased, and forage digestibility likewise decreased. Thus, the nutritive value of a plant is dependant on tiller age at the time of sampling.

2.4.5 Animal Intake and Utilization

The utilization of forage largely reflects particle passage rate (Marten 1969), which in turn, is a function of digestibility. As a result, high forage production does not always translate to improved

animal performance if forage quality parameters and associated digestibility are sacrificed (Beatty and Engel 1980). Walton and Gesshe (1981) illustrated that grazing animals show preference for heterogeneous plant communities and select for low crude fiber, and high crude protein, moisture and overall digestibility. Greater intakes have been shown for legumes than grasses (Ulyatt 1981). Samuel and Hart (1980) showed that improvements in range utilization were related to increases in forage quality and palatability. The same study suggested that cattle exhibit a preference for fertilized range over non-fertilized range when the two are contiguous. Cattle may travel moderate distances to graze range that is fertilized. The implication of this on range utilization and distribution may be considerable. The addition of nutrients to grassland has the potential to promote more uniform grazing by enhancing the palatability of most species and thereby reducing the proportion of un-grazed or lightly grazed plants (Cook 1965). Additionally, fertilization tends to cause plants to green up earlier in the spring and remain green and succulent longer into the fall (Bezeau et al. 1968; Johnston et al. 1967), provided moisture is available for growth to continue. The increase in production per annum can facilitate increases in stocking rates and/or lengthen the grazing season, thereby increasing the effectiveness of range utilization and livestock production.

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Chapter Three

Herbage Production and Quality Within Four Perennial Plant Communities Following Liquid Hog Manure Application

3.1 Introduction

Over the last decade, there has been a change in the demographics of commercial hog production in Alberta from smaller to larger operations (AAFRD 2000). Notably, this expansion has included the semi-arid region of the province where land is marginally productive and largely uncultivated. This trend is driven, in part, by an effort to avoid potential conflict with urban municipalities and other land users over issues such as odor. Further expansion is likely, especially if Alberta wants to become both a North American and global force within the hog industry (Church 1997; Perkins 1997).

Animal manure, an abundant by-product of intensive livestock operations (ILOs), has historically been applied to cultivated lands to enhance the production of annual crops. However, the transport of manure from newly established hog operations in south-central Alberta to cultivated lands is not always feasible from both a logistical (time) and economic (transport cost) perspective. Instead, adjacent perennial forage lands may constitute the most practical sink for liquid hog manure (LHM). Perennial forage lands include both native rangelands, which are more common in arid and semi-arid regions, as well as seeded tame pastures, which occur throughout the agronomic (e.g., cultivated) area of the province.

Sustained production of abundant, high quality forage is a prerequisite to beef cattle production and consequently, the success of commercial ranch operations. Research in western North America indicates that above–ground herbage yield increases with nutrient addition on both native rangelands (Jacobsen et al. 1996; Read 1969; Johnston et al. 1968a; Johnston et al. 1967) and tame pastures (Bittman et al. 1997; Lutwick and Smith 1977; Johnston et al. 1968a). The magnitude of yield response to nutrient addition, however, is variable depending on pre-treatment soil nutrient

levels, vegetation type, and seasonal growing conditions (Belanger and Gastal 2000; Power 1985). Growing season and previous year's precipitation are both pivotal in determining forage yield in natural rangeland communities (Smoliak 1986). Vegetation response to N addition is correlated with pre-treatment soil moisture and growing season precipitation (Johnston et al. 1969). Kilcher (1958) demonstrated that the yield response of cultivated grasses to N fertilizer in southern Saskatchewan was constrained by moisture status, particularly May precipitation, suggesting that N addition can only enhance pasture production if moisture is not limiting. Other research (e.g., Guevara et al. 2000) also indicates that nutrients limit above-ground yield when moisture is non-limiting, with the threshold occurring between 300 and 400 mm precipitation on coarse, sandy soils.

In general, the absolute above-ground net primary production (ANPP) response of native rangelands to nutrient addition is smaller than adjacent seeded forages (Johnston et al. 1968a). Relative changes in ANPP, however, may not differ between native and tame forage lands treated with nutrients under similar conditions. Alternatively, native rangelands may respond to nutrient addition by increasing below-ground root production (Goetz 1969; Lorenz and Rogler 1967), translating into greater water extraction, particularly at greater depths, and enhanced water use efficiency (WUE) as well as gains in long-term ANPP (Smitka et al. 1965). The ability to extract soil moisture more effectively may also enhance the ability of vegetation to cope with moisture stress (e.g., drought resistance and resilience).

Despite the increase in forage production that can be obtained, the practice of nutrient application has not been widely implemented on native rangelands due to the high cost associated with commercial fertilizers (Rubio et al. 1996; Godfrey and Wight 1985). There is also a pervasive philosophy that native rangelands are self-sustaining, low-input communities that are unsuitable for intensive management. In semi-arid regions, rangelands (along with adjacent tame pastures) frequently lack the favorable edaphic and climatic conditions necessary (e.g., sufficient and stable levels of precipitation) for the successful use of nutrient amendments (Rubio et al. 1996; McCaughey and Simons 1996).

The majority of previous research evaluating the response of native rangelands to nutrient addition has utilized commercial fertilizers (e.g., Wight and Black 1979; Johnston et al. 1968a, 1967). In a rare exception, solid beef manure was applied to southern Alberta Mixed Prairie to evaluate vegetation responses (Smoliak 1965). On tame pastures, research evaluating the response of vegetation to liquid manure application is more common, but that work has typically been performed outside the province of Alberta (e.g., Pastl et al. 2000; Bittman et al. 1997). One recent study in Saskatchewan illustrated the use of LHM injection technology onto tame pastures of crested wheatgrass, smooth brome/alfalfa, and Russian wildrye, with favorable ANPP responses (Pastl et al. 2000). Initiatives within Alberta have been limited to more mesic areas, including irrigated lands (AFMRC 1999).

Given the paucity of information addressing the application of LHM to forage lands, particularly in the semi-arid dryland region of Alberta - including native rangelands, original research is needed to quantify the response of Alberta's perennial forage lands to LHM application parameters. A clearer understanding is also needed of the differential response between native rangelands and tame pastures. Where research finds that LHM application is consistent with maintaining (or enhancing) the productivity of herbage and/or forage quality, practical guidelines are needed to establish appropriate manure application rates and methods that promote commercial agricultural production, while protecting the long-term sustainability of these forage lands. This experiment tested the effects of three main factors, including rate of LHM application, method of LHM application (injected VS dribble broadcast) and season of LHM application (fall VS spring). The primary goal of this initiative was to determine forage yield and quality responses as a function of these factors and their interactions. A secondary objective included contrasting responses among different types of perennial vegetation, including both native rangeland and tame pasture, under both xeric and mesic moisture regimes.

3.2 Methods

3.2.1 Study Sites

This research was conducted in south-central Alberta, near Little Fish Lake (51°22'N, 112°13'W) (Apppendix A-I). The area is approximately equidistant from the municipal centers of Hanna (northeast) and Drumheller (southwest). Topography of the region is gently undulating with well-defined plateaus and valleys, at an average elevation of ~800m above sea level. The climate of the region is continental, with warm summers and cold winters. The 30-year average precipitation compiled from the nearest weather station at Craigmyle, Alberta (30 km north of the study area) shows a semi-arid mean annual precipitation of 394 mm. Growing season precipitation (May to August inclusive) averages 217 mm. The mean annual temperature is 3.1 °C, with May to August temperatures averaging 10.3, 13.9, 16.1 and 14.8 °C, respectively (Environment Canada 1993). There is, however, a great deal of inter-annual variation in growing conditions.

Due to variability in terrain and elevation, there are marked landscape-based differences in effective moisture regimes and resulting soils. Mesic areas have Dark Brown to Black Chernozems (Typic Haplustoll Series), whereas xeric sites are typically shallow Brown Chernozemic soils (Aridic Haplustoll Series). In addition, the geographic location of the study area represents the juxtaposition of two distinct ecoregions: Mixedgrass Prairie and Aspen Parkland, the latter of which includes northern Fescue Grasslands (Strong and Leggat 1992) (Appendix A-I). Four unique study sites were examined in this study, representing the range of plant communities, including native rangelands representative of the xeric Mixed Prairie (MP) and mesic Fescue Grassland (FG). Specific range types on the MP and FG sites are representative of the *Stipa-Agropyron* and *Festuca-Stipa* faciations, respectively (Coupland 1992b, 1992a, 1961). To contrast with these native rangeland communities, two seeded pastures were examined, including an Alfalfa (*Medicago sativa* L.)-Meadow Brome (*Bromus biebersteinii* Roem & Schult.)-Crested Wheatgrass (*Agropyron cristatum* (L.) Gaertn.) sward seeded in ~ 1997 on a mesic Black Chernozem, the other a xeric Brown Chernozem with a stand of Crested

Wheatgrass (*Agropyron cristatum* (L.) Gaertm.)-Alfalfa (*Medicago sativa* (L.)-Russian Wild Rye (*Elymus junceus* Fisch.) established in ~ 1986. The latter 2 sites will hereafter be referred to as the Meadow Brome (MB) and Crested Wheatgrass (CWG) sites, respectively.

All sites were selected in 1998 and chosen on the basis of their internal homogeneity of range site conditions and vegetation expression. All research sites were in good to excellent range condition (e.g., not overgrazed). Both native communities were utilized for dormant season grazing from mid-October through mid-December at low stocking rates (e.g., ~ 1.1 AUM/ha), with hay supplemented in December. From March 27 through April 30th of both 1999 and 2000, the pasture containing the CWG site was used as a calving pasture, with higher stocking rates (e.g., ~ 4.0 AUM/ha). Only the MB site saw differential management between 1999 and 2000. In 1999, this pasture was hayed (except the study site), then subsequently grazed from September 15th through October 15th at a stocking rate of 0.45 AUM/ha. In the summer of 2000, this same area was grazed for 5.5 consecutive months at a stocking rate of 2.7 AUM/ha. It is important to note that for each of the four study sites, the stocking rates are for the entire field, and not for the research site itself. Total field areas are 64.8 ha for the CWG, and 388.5 ha for each of the MB and winter fields, the latter of which encompasses both the FG and MP sites.

3.2.2 Manure Treatments

Each research area was equal in size (150×50m), and divided into 23 treatment plots, each 7×50 metres in size (Appendix A-II). Treatments were designed to examine three facets of LHM application: rate (10, 20, 40, 80, and 160 kgNH_3-N.ha^{-1}), method (dribble broadcast vs. injection), and season (fall vs. spring). Twenty possible treatment combinations were randomly applied to each of the four plant communities. In addition to the treatment combinations, there were 3 controls at each site, two of which were dry passes of the injection equipment (one in the fall and one in the spring), and one of which was a true control (e.g., no treatment or equipment disturbance). Following completion of treatment applications, each study site was fenced in late-April of 1999 to exclude

livestock. However, on each of the 4 sites, a 150×15 m area was left outside the fence in an attempt to assess cattle utilization relative to the treatments (Appendix A-II).

LHM was applied to study sites using the Greentrac slurry injection system, owned and operated by the Prairie Agriculture Machinery Institute (PAMI) in Humbolt, Saskatchewan. Fall LHM treatments were applied between October 5th and 7th, 1998, with the spring treatments applied between April 12th and 14th, 1999. Coulters on the Greentrac were spaced at 25 cm, and each plot had a half-meter buffer on every side. Where LHM was injected into the soil matrix, injection was to a maximum depth of 10 cm, but averaged 7.5-10 cm. Surface applications were made using the same machinery, with adjustments made so LHM was dribbled onto the ground surface from a height of ~ 30 cm. In this respect, Greentrac broadcast treatments differed from more traditional 'splash-plate' broadcast treatments in terms of manure atomization and susceptibility to atmospheric drift losses.

In order to ensure LHM treatments were as consistent as possible, LHM samples were taken from the storage lagoon and analyzed for nutrient content two weeks prior to each application date. Using this information, the Greentrac applicator was calibrated and tractor speed adjusted accordingly. Each load of LHM during the treatment application phase was sampled and subsequently tested for nutrient content to ensure consistency among loads. Sample manure nutrient data from the spring 1999 applications are presented in Appendix B-I. Despite intensive testing and calibration, actual application rates were slightly lower (~5%) than target application rates. This subtle discrepancy is likely an artifact of either changes in manure nutrient content between the time of sampling and treatment, or possibly nutrient differentials related to location of manure extraction from within the storage lagoon. Theoretical and actual (adjusted) rates for both spring and fall applications are presented in Table 3.1, along with the water depth equivalents for each treatment.

3.2.3 Vegetation Sampling

Within each plot at each of the four sites, ANPP was measured at peak standing crop during the successive growing seasons of 1999 and 2000 following the one-time manure application.

Sampling was carried out from June 28–July 24, 1999 and July 08–August 02, 2000 on tame pastures. Native rangeland vegetation, which is slower to commence active growth and reach maturity, was sampled from August 15–26, 1999 and August 19-24, 2000. Within each plot, all ANPP was clipped in four randomly located ($0.5m^2$) quadrats, and subsequently separated by growth form. Clip samples were separated into grass, forb, and shrub components on native sites, and perennial grass, alfalfa, and weed (mostly short-lived annual) components on seeded pastures. Both native plant communities lacked annual weeds even at high rates of manure, and as a result, weeds were not clipped at either the FG or MP sites. All sub-samples were oven-dried (at 60^0C), weighed and converted to ANPP values in $kg.ha^{-1}$. Study sites were opened for grazing and litter removal following data collection in both 1999 and 2000.

To assess forage quality, 2 of the 4 clipped quadrats on each treatment plot (excluding the controls) were randomly selected for both grass and forb (or alfalfa) components. In 1999, both forb (MP & FG) and alfalfa (CWG & MB), as well as grass samples from all sites, were ground using a Wiley mill to pass a 1 mm screen, and analyzed for crude protein (CP), acid detergent fiber (ADF) and phosphorus (P) content. As a result of below-normal precipitation in 2000, the quantity of forb/alfalfa production was insufficient for quality analysis of these components on all but the MB site. Weed and shrub ANPP were insufficient for quality analysis in both years.

Crude protein yield (CPY) was also determined for the graminoid component on each of the four study sites in 1999 and 2000. Alfalfa CPY was calculated for the MB site only, as this site was the only plant community producing sufficient alfalfa (forb) in both years of sampling. CPY is calculated by multiplying CP by ANPP, and may be a better index of overall forage response to LHM application than either ANPP or CP alone, as it contains both a quality and quantity component.

Limited forage utilization data was also collected in an effort to discern whether cattle preferentially selected (or avoided) forage treated with LHM. This data collection was restricted to 1999 on the two tame pastures, which have historically been used for spring grazing, but was further constrained to the CWG site following haying of vegetation outside the MB exclosure. Utilization

was determined using 2 sets of paired quadrats within each treatment plot. Quadrat pairs were located both inside and outside the exclosure fence within a plot. This process allowed direct comparison of maximum herbage ANPP within the exclosure to depleted standing herbage following grazing. The difference between quadrat pairs was determined, averaged between pairs, and the difference subsequently analyzed (expressed as an absolute value).

3.2.4 Analysis

The fundamental experimental design of this research was a randomized block, with the 4 sites as replicates. Analysis using this design would have facilitated testing of main treatment effects, but precluded evaluation for site-based differences as each site contained unreplicated multi-factor treatment combinations. Because of this restriction and the interest in assessing for differential treatment effects between sites, particularly native rangeland and tame pasture, the application of traditional statistical analyses (e.g., ANOVA) was considered less suitable. Instead, an alternate procedure was used that employed trend analysis and partitioning of variance from each multi-factor treatment combination through a series of orthogonal contrasts using Proc IML within SAS™. Half normal plots were subsequently employed to determine which component(s), if any, were significant (Milliken and Johnson 1989). Due to the lack of replication within each site, significance was not assessed in terms of p-values, but rather, distinguished based on their relative distribution to one another within the half normal plot. Significant treatment effects were then expressed in graphical form using trend analysis. A complete example of the use of Proc IML and half-normal plots is located in Appendix C.

3.3 Results and Discussion

3.3.1 Growing Season Conditions

Seasonal growing conditions in 1999 were favorable for plant growth, with precipitation across the study area during May 27–August 24, 1999, totaling 284 mm (averaged over all four sites).

This value is above the long-term average from Craigmyle, Alberta, which shows mean precipitation for May to August inclusive at 219 mm (Environment Canada 1993). Given that the 284 mm represents a conservative estimate tempered by evaporative losses and the lack of data for the early part of May, a time when plant growth is vigorous, 1999 represented a relatively mesic growing season, ~30% greater than the long-term regional average.

In 2000, dry conditions prevailed, and precipitation over the period May 03–August 15, 2000 totaled 106 mm (averaged over all four sites). Although this total represents a conservative estimate for growing season precipitation, 2000 was clearly below the long-term normal (e.g., -40 to -50%).

3.3.2 Above-ground Net Primary Production

Overall ANPP responses to the different seasons, rates, and methods of LHM application are presented in Tables 3.2 through 3.4. Mean above-ground net primary production and standard deviations for all main treatments in both years of the study are contained in Appendix D-I.

3.3.2.1 Season of LHM Application

Responses to different seasons of LHM application (e.g., spring vs. fall) were very limited, with the sole significant effect limited to alfalfa ANPP on the MB site in 1999 (Table 3.2). Examination of the data indicated spring treatments yielded an average of 4042 (+/- 1316) $kg.ha^{-1}$ of alfalfa compared to the fall treatments at 3042 (+/- 1529) $kg.ha^{-1}$. This finding suggests that nutrients applied in the spring just prior to active growth may be more beneficial for alfalfa. One possible explanation is that grasses may immobilize nutrients better during periods of slow growth (eg. dormancy), placing alfalfa at a competitive disadvantage with fall application. Alternatively, alfalfa may be less able to take up and assimilate nitrate than ammonium, as fall applied ammonium in manure appears to be converted during the winter through nitrification (Brian Lambert, unpublished data). Thus, the timing of application may be important if the maximization of alfalfa production is an important objective. Other trials involving nutrient addition found that the most

important variable when considering season of application is the timing relative to active photosynthetic growth (Campbell et al. 1986). Overall, the limited response of ANPP to different seasons of LHM application suggests that differences between fall and spring applied treatments may be negligible.

3.3.2.2 Rate of LHM Application

Initial (1999) graminoid production responded positively to increasing rates of LHM application at all sites except the MB plant community (Tables 3.2 to 3.4; Figure 3.1). All 3 sites with significant rate effects exhibited a linear response trend in graminoid production (Figure 3.1). Graminoid production varied from 580 to 4439 $kg.ha^{-1}$ on the CWG site as target manure application rates increased from 10 to 160 $kgNH_3$-$N.ha^{-1}$ (Figure 3.1). Native rangeland plant communities responded similarly, significantly increasing graminoid ANPP from 1963 to 4112, and from 740 to 2228 $kg.ha^{-1}$ on the FG and MP sites, respectively (Figure 3.1).

Although no significant graminoid ANPP response was observed at the MB site, the data in Figure 3.2 suggests there may have been a positive response, but only at low levels of manure application (up to 40 $kg.ha^{-1}$). This trend was not sufficient to produce a significant quadratic response (Table 3.2), however, possibly due to localized variability in plot responses or the limited magnitude of production increase.

Despite the lack of grass response, the alfalfa component of the MB community did respond significantly to the rate of LHM application in 1999 (Table 3.2). Although linear in nature (Table 3.2), the response was negative and characterized by the greatest decline in alfalfa ANPP as rate of LHM application increased to 40 $kg.ha^{-1}$ (Figure 3.2). These findings are in agreement with relevant literature, which suggests alfalfa yield is subject to decline with increasing N application (Bittman et al. 1997; Dougherty and Rhykerd 1985; Lutwick and Smith 1977). This response pattern is likely an artifact of nutrient addition increasing the yield and relative proportion of non-leguminous plants (Hannaway and Shuler 1993), particularly grasses, which increases competition from those species

and may generate decreases in alfalfa yield. Application of (fertilizer) N to leguminous plants has rarely generated increases in yield, due in part, to depression of nodulation and N fixation of the legumes (Dougherty and Rhykerd 1985). Figure 3.2 clearly illustrates the inverse relationship between alfalfa and graminoid components within the MB site as the rate of LHM increased.

In contrast to the strong positive response of grass production in 1999 on both native rangeland sites, initial forb responses to increasing LHM application rates were less consistent. The MP site did increase forb production linearly as LHM application rate increased (Table 3.2; Figure 3.3). A large proportion of this response could be attributed to an increase in the cover of pasture sage (*Artemisia frigida* Willd.) (See Chapter 4). Other studies have demonstrated that this species is able to capitalize on nutrient additions and exhibit a yield response, particularly in the first growing season after treatment (Kilcher et al. 1965; Goetz 1969). Although increases in this unpalatable half-shrub are not desirable from a land manager's perspective, research also suggests that this response is short-term in nature (Kilcher et al. 1965), thereby posing little risk to the long-term productivity and sustainability of these communities.

Although the MP site also appeared to show a residual forb production response to manure rate in 2000, this response was not statistically significant. Notably, forb production visibly decreased with increasing rates of LHM application the year before (Figure 3.3), providing evidence that the increase in forb production the year before was temporary. This negative trend also suggests that the initial positive responses within the graminoid component in 1999 at high manure rates may have subsequently increased competition between grass and forb components. Increased competition from grasses, particularly that taking place in the rooting zone for space, moisture, and nutrients, would limit future forb ANPP responses at high LHM rates. Forbs have been found to be more shallow-rooted on average (Brown 1995), and thus, may be less effective competitors against the extensive root systems of grasses that develop at high rates of LHM application (Dougherty and Rhykerd 1985; Viets 1962).

Though one eminent concern related to LHM application, was the potential for a sizable increase in annual weeds and invasive species at high rates of N, this was not substantiated based on the results of this research. Annual weeds were limited to the two tame pastures, and did not appear within either the FG or MP sites. Although weed ANPP did increase (from 23 to 58 $kg.ha^{-1}$) with accelerating rates of LHM on the MB site, this response was not significant and was limited to the first year of monitoring (e.g., 1999). It is likely that the dense cover of alfalfa and perennial grasses within this plant community effectively competed against any weed species for resources and thus, limited the magnitude of weed response (Pysek and Leps 1991).

Generally, residual responses to increasing rates of LHM application were very limited for both forb/alfalfa and grass ANPP in 2000 at all sites (Tables 3.2 to 3.4). This result is somewhat surprising given that other research has found one-time nutrient application can have residual yield benefits that are equally or more important than initial (immediate) yield gains (Pastl et al. 2000; Jacobsen et al. 1996; Read 1969; Smith et al. 1968). Residual yield responses have been reported for established seeded forages (e.g., Pastl et al. 2000), as well as for xeric native rangelands (e.g., Jacobsen et al. 1996). Residual responses may be limited to xeric communities where nutrient leaching is not an issue (Willms and Jefferson 1993), and nutrients are likely to remain in the soil or within below-ground plant parts for several years (Power 1970).

The only exception to the lack of effects in the second year was found on the MB pasture, where the interaction of manure rate (quadratic trend) and season elicited a significant alfalfa yield response (Table 3.2). This response is shown is Figure 3.4 and given its complex nature, maybe spurious.

Poor second year responses to the one-time LHM application(s) in this investigation could be attributed to several factors. First, the most limiting factor to plant production, particularly in prairie environments, is water availability (Barker et al. 1989). In 2000, precipitation was lower than normal. Second, nutrients added to the study sites may have been mostly utilized during the 1999 growing season by the lush, productive swards that year, especially with above-normal precipitation.

Third, soil microbes may have immobilized any residual nutrients remaining in the soil, rendering them inaccessible for plant growth in the short-term. Fourth, other research has shown that forage plants will often store nutrients below-ground, especially in a time of stress such as drought (Lutwick and Smith 1977; Power 1970), indicating some nutrients may have been stored within plant root systems. Fifth, despite grazing during the fall and winter within the plots, ANPP response in 2000 may have been affected by increased standing litter from the previous year's growth, a factor that could have altered the microenvironment of the sites and limited yield response.

3.3.2.3 Method of LHM Application

While rate of LHM application clearly affected immediate (1999) ANPP responses across all sites, vegetation responses to the two methods of LHM application were negligible. None of the ANPP parameters measured at any of the four research sites showed a significant response to method of LHM application. Despite this, the MP site did appear to have a marginal yield response to method of LHM application in 1999, with both forb and grass ANPP increasing within injected treatments (512 and 1411 $kg.ha^{-1}$, respectively) relative to the surface broadcast treatments (396 and 1129 $kg.ha^{-1}$, respectively). Sample size limitations may have prevented a significant effect from occurring. It is also notable that in no case did injection reduce ANPP yields, regardless of the site (Appendix D-I), indicating the disturbance associated with injection was not detrimental to the plant communities examined. Other benefits may also exist to utilizing injection, such as a reduction in nutrient loss via ammonia volatilization (Brian Lambert, unpublished data). This, in turn, could induce greater root growth at deeper soil depths, and promote water-use efficiency relative to surface broadcast treatments.

3.3.3 Forage Quality

Overall forage quality responses, including CP, ADF, and phosphorus, to season, rate, and method of LHM application are presented in Tables 3.5 and 3.6. Mean forage quality and standard deviations for all main treatments over both years of the study are presented in Appendix D-II.

3.3.3.1 Season of LHM Application

Season of LHM application failed to generate significant changes in forage quality during either 1999 or 2000. This result suggests that application either in early spring (e.g., April) or fall (e.g., October) will achieve similar results in terms of anticipated forage quality. It is important however, to point out that both times of application employed within this experiment were alike in that they occurred prior to active (e.g., photosynthetic) growth. Thus, the lack of differences does not test the possibility that application of nutrients to forages prior to active growth leads to either superior or inferior capture of nutrients by the plant community relative to applications during active growth or applications onto snow cover (Wilkeen et al. 1989).

3.3.3.2 Rate of LHM Application

Graminoid CP content increased with rate of LHM application in 1999 on all sites with the exception of MP (Table 3.5 and 3.6). CP response to manure rate indicated the response was linear in each case (Figure 3.5). This pattern concurs with other studies that have found increases in CP are directly proportional to the rate of N application (McCaughey and Simons 1999; Bezeau et al. 1967). Samuel et al. (1980) found that livestock (e.g., cattle) select forage that exhibits high forage quality parameters including crude protein (CP) and digestibility, factors that can be enhanced by fertilization.

Analysis of ADF also showed a significant linear trend as rate of LHM application increased, but only within the MB plant community in 1999 (Table 3.6). As might be expected, the trend was opposite that of CP, with a decline in ADF as rate of manure increased (Figure 3.6).

Residual effects on forage quality from various rates of LHM application were limited in 2000. The sole significant effect occurred within the MB community (Table 3.6), where the graminoid component showed a significant linear response characterized by a marked increase in CP at the maximum level of LHM application (Figure 3.7).

Crude protein (CP) increases observed here may have been the direct result of the addition of readily available nutrients within the LHM, particularly N. Nutrient additions can also alter the phenology of forage plants, with initiation of growth earlier in the season and delayed senescence during the growing season (Johnston et al. 1968b, 1968a, 1967). This results in more succulent vegetation over a longer time period, which translates into greater overall forage quality at a fixed sampling date. Undoubtedly, the increase in forage quality in 1999 was also facilitated by ample moisture during the growing season that allowed plant growth to continue uninterrupted.

3.3.3.3 Method of LHM Application

Neither method of LHM application, nor its interactions with the other main effects, had a statistically significant effect on any of the forge quality parameters examined in either year of data collection. This finding is similar to the yield data and suggests that there is no comparative agronomic advantage to utilizing one mode of application over the other.

3.3.4 Crude Protein Yield

Crude protein yield (CPY) responses to season, method, and rate of LHM application are presented in Tables 3.7 and 3.8. Mean crude protein yield and standard deviations for all treatments in both years of the study are presented in Appendix D-III.

3.3.4.1 Season of LHM Application

Season of LHM application had no discernable impact on CPY for either grass (all sites) or alfalfa (MB site) in either 1999 or 2000. This result suggests once again that different seasons of application (e.g., spring vs. fall) do not markedly affect forage responses.

3.3.3.2 Rate of LHM Application

Rate of LHM application significantly affected graminoid CPY on all sites in 1999, with positive linear increases in CPY as the rate of LHM application increased (Table 3.7; Figure 3.8). While these results are not unsurprising as they are similar to those of yield and CP alone, it is notable that all 4 sites demonstrated these significant differences. Thus, it appears that for some sites at least, the variable of CPY is more responsive to LHM than CP or yield alone. Perhaps even more important, residual CPY responses in 2000 followed the same pattern on all sites with the exception of FG (Table 3.8; Figure 3.9). This suggests that subtle increases in graminoid quality (e.g., CP) and yield, while not sufficient enough to generate individual quality or yield responses, had a multiplicative effect when factored into CPY. Furthermore, the residual CPY response indicates long-term forage responses were evident in this study despite xeric growing season conditions in 2000. Thus, there appears to be a lasting benefit to LHM application, even when growing season conditions are sub-optimal.

Alfalfa CPY was examined on the MB study site in both 1999 and 2000 to determine whether accelerating rates of LHM application enhanced the CPY of this important forage species. In both 1999 and 2000, rate of LHM application failed to generate any appreciable response in alfalfa CPY. This result suggests that much like ANPP, alfalfa CPY is unlikely to be improved by higher rates of LHM application. However, it is difficult to determine how much of the lack of a response is due to 1) limited alfalfa response potential, or 2) competitive interactions with the graminoid

portion of the forage sward. To address this, future research should consider addressing the CPY response of leguminous plants when grown with and without companion grass species.

3.3.4.3 Method of LHM Application

Method of LHM application had no affect on CPY of either alfalfa (MB site) or graminoid (all sites) in either year of this research (Appendix D-III). The lack of significant differences in CPY between surface and sub-surface applied treatments should be interpreted with some degree of caution as the benefits of injected technologies may have been too subtle to detect here, but still amount to considerable economic benefits once applied over large areas.

3.3.5 Forage Utilization

Livestock response (e.g., utilization) to forage treated with LHM was examined on the CWG site in 1999. No main treatment effects or combinations thereof were detected, with cattle utilization similar between treated and untreated areas. Other research has suggested that livestock (e.g., cattle) may exhibit an affinity for forage treated with nutrient amendments, because such forage often has enhanced CP and palatability (Samuel et al. 1980; Cook 1965). Despite this, no utilization trends were apparent in this study. Although manure application may not have affected animal preference and use on the sites examined, other explanations exist for why no utilization differences were found in this investigation. For example, cattle utilization was likely far from uniform, particularly in such large pastures (e.g., up to 386 ha). Similarly, the sampling intensity of 2, 0.5m^2 quadrats per plot may have been too sparse relative to the patchy utilization within plots to detect overall utilization differences between treatments. Appendix D-IV shows mean utilization across treatments on the CWG site for both the alfalfa and grass components of the sward.

3.4 Management Implications

LHM application on perennial forage lands presents the land manager with another opportunity to enhance herbage production, while simultaneously disposing of manure. Within the context of this research, and within the scope of other research, the application of nutrients through LHM generated positive responses in terms of both forage yield and quality. For the land manager, these results translate into higher stocking rates, potentially more uniform grazing (Cook 1965) and in general, a greater efficiency of land use.

This research has demonstrated that vegetation response is most closely linked to the rate of LHM application, more so than either the season or method of application. Agronomic response (e.g., forage quality and quantity) increased linearly with increasing rate of LHM application, particularly in the first year following manure application. However, over both years of this study, there was a general lack of significant responses to either of the other two independent variables. Season of LHM application appeared to have an impact on alfalfa ANPP within the MB pasture, with 1999 alfalfa yield increasing with spring application. This response was reversed in 2000, as alfalfa had a significant rate by season response with alfalfa yields bolstered by fall applications more than a year before. Further research may be needed to determine how both immediate (first year) and residual (second year) alfalfa yield responses are affected by season of application.

While the injection technology supplied by PAMI did not elicit many (significant) agronomic (yield and quality) responses, and the cost and draft power needed to operate such machinery may deter its future use, this decision should not be made hastily because there may be other important benefits to using injection technology. Injection of LHM may reduce nutrient losses via volatilization. Research on perennial forage crops in coastal British Columbia has illustrated that mode of application may promote more consistent crop responses (Bittman et al. 1999). For smaller-scale operators, delivery of consistent returns from land application of LHM (or other slurry) is key to the effective utilization of this resource. Bittman et al. (1999) contrasted crop response to splash-plate application and surface-banded (sleigh-foot) application, and found that less nutrients

were required when using the latter technology, and that this technology was more effective in reducing nutrient loss. Reduced nutrient loss means greater efficiency of nutrient capture, which could induce greater root proliferation and promote water-use efficiency for the entire plant community, which would be very advantageous in semi-arid regions,. Furthermore, injection technology may reduce the severity of odor, a factor that is apt to be an issue in both urban and rural municipalities as hog industry expansion continues.

Although absolute increases in herbage production were greater on tame pastures in this study, relative yield responses were consistent across vegetation types including native rangelands and tame pastures. These results indicate that agronomic benefits can be obtained from both land bases through the application of LHM, which in turn, may enhance opportunities for livestock grazing and beef production. This finding also dispels the notion that rangelands are relatively unresponsive to management activities such as nutrient addition. Although herbage ANPP and quality lacked residual responses to LHM application in this study, residual CPY effects were very evident despite the occurrence of drought. Similarly, other long-term benefits may exist for the plant community including the condition of below-ground roots. Finally, no prominent negative impacts on overall yield were observed at high end LHM application rates, regardless of the plant community, indicating that damage to the vegetation did not occur under the treatment conditions examined.

Land managers who choose to apply LHM to their lands need to be cognizant of response differentials between various plant communities. Response is driven by the production potential of a plant community, a character that is genetically predisposed (Barker et al. 1989), coupled with the local moisture regime and the initial condition (e.g., vigour) of the plant community. As a general rule, seeded forages have a greater production potential as determined through genetic selection for increased yield, and will likely accrue greater absolute increases with LHM application relative to adjacent native rangelands. Similarly, xeric plant communities will have lower production potentials and limited absolute increases in yield relative to more mesic communities. Thus, the application of LHM to forage lands should be approached on a site-by-site basis.

The results of this research clearly highlight the fact that different forage lands, including both native rangeland and tame pasture, are capable of utilizing nutrients applied within LHM, even at application rates as high as 160 kg.ha^{-1}. However, given that precipitation is highly variable in this environment, and that moisture generally limits the potential for plant growth (Smoliak 1986, 1965), it is likely that manure application rates should be adjusted yearly to match plant demands, and will generally be much lower than the maximum used in this investigation (e.g., ~40 kg.ha^{-1}). In fact, it is possible that the magnitude of yield response would have been much lower had application occurred in the fall and spring of 1999 and 2000, respectively, when low moisture availability could limit yield responses to added N (Kilcher 1958, Johnston et al. 1969). Although sizable increases in ANPP may be lacking in such years, there may still be a benefit to applying LHM. Nutrients applied during dry years may be stored below ground, or alternatively, may enhance below-ground root growth (Wight and Black 1979), translating into increased WUE, and an ability to extract more water from a greater depth relative to untreated vegetation. Alternatively, increased WUE may promote drought susceptibility by allowing plants to tap into moisture reserves with greater efficiency, potentially exhausting the plant-available water supply more rapidly. Further research is needed in this regard to examine plant below-ground and WUE responses to nutrient additions. Yield increases may also last considerably longer under these circumstances, as nutrients would be depleted slowly or bound up within the soil through immobilization and released slowly through time.

3.5 Conclusion

This research confirms earlier studies that indicate the application of nutrients through manure has the potential to enhance agronomic production, primarily herbage yield. Forage yield and quality responses were, however, constrained to the first year of investigation (e.g., 1999) and were further limited mainly to the graminoid fraction. Although rate of application significantly affected herbage yield, forage quality and CPY, relatively few responses were found to either the method of manure application (injection VS broadcast) or the season of application (fall VS spring).

Residual responses of either quality or yield were negligible. This result may lead to speculation that seasonal growing conditions (e.g., moisture availability) may ultimately determine the potential response of plant communities to LHM application. Crude protein yield, however, did show a significant residual response on most study sites, suggesting that forage performance can benefit from prior LHM applications even when growing season conditions are less than optimal.

Further research is recommended to examine the response of LHM application on a greater variety of perennial forage lands, as well as under a wider variety of seasonal growing season parameters and plant community conditions or historical use patterns. The results of this study are supportive of the notion that LHM application to forage lands is agronomically beneficial on both tame pastures and native rangelands. Furthermore, from an agronomic (e.g., forage yield and quality) perspective, the observed responses suggest that the more LHM applied the greater the increase in forage. In this regard, environmental concerns withstanding (see Chapter 4), high end LHM application rates may be the most desired for generating the greatest magnitude of positive agronomic benefits.

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Table 3.1: Target and actual LHM application rates and associated water depth equivalents for each season of application.

	Spring Application 1999		Fall Application 1998	
Target Application Rate (kgNH3-N.ha^{-1})	**Actual Application Rate (kgNH3-N.ha^{-1})**	**Water Depth Equivalent[1] (mm)**	**Actual Application Rate (kgNH3-N.ha^{-1})**	**Water Depth Equivalent[1] (mm)**
10	9.5	1.1	9.3	1.3
20	19.0	1.1	18.6	1.3
40	37.9	2.1	37.1	2.7
80	75.8	4.2	74.2	5.3
160	151.6	8.4	148.4	10.7

[1]Note: water depth equivalents for application rates of 10 and 20 kgNH3-N.ha^{-1} are the same because application rates involved LHM, and ½ water + ½ pure LHM (dilution factor) for the 20 and 10 application rates, respectively.

Table 3.2: Summary of significant ANPP responses by growth form within the Meadow Brome-Alfalfa site in 1999 & 2000.

Factor[1]	**1999**			**2000**		
	Graminoid	**Alfalfa**	**Weeds**	**Graminoid**	**Alfalfa**	**Weeds**
Method	ns	ns	ns	ns	ns	ns
Season	ns	**significant**	ns	ns	ns	ns
LIN_rate	ns	**significant**	ns	ns	ns	ns
QUA_rate	ns	ns	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns	**significant**	ns
LIN3	ns	ns	ns	ns	ns	ns

[1] Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*season, FOR*meth, FOR*season, QUA3, CUB3, FOR3, and season*method

Table 3.3: Summary of significant ANPP responses by growth form within the Mixed Prairie and Fescue Grassland in 1999.

Factor[1]	Mixed Prairie			Fescue Grassland		
	Graminoid	Forb	Shrub	Graminoid	Forb	Shrub
Method	ns	ns	ns	ns	ns	ns
Season	ns	ns	ns	ns	ns	ns
LIN_rate	**significant**	**significant**	ns	**significant**	ns	ns
QUA_rate	ns	ns	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns	ns	ns
LIN3	ns	ns	ns	ns	ns	ns

[1] Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth CUB*season, FOR*meth, FOR*season,QUA3, CUB3, FOR3, and season*method

Table 3.4: Summary of significant ANPP responses by growth form within the Crested Wheatgrass-Alfalfa site in 1999 & 2000.

Factor[1]	1999			2000		
	Graminoid	Alfalfa	Weeds	Graminoid	Alfalfa	Weeds
Method	ns	ns	ns	ns	ns	ns
Season	ns	ns	ns	ns	ns	ns
LIN_rate	**significant**	ns	ns	ns	ns	ns
QUA_rate	ns	ns	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns	ns	ns
LIN3	ns	ns	ns	ns	ns	ns

[1] Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*season, FOR*meth, FOR*season, QUA3, CUB3, FOR3, and season*method

Figure 3.1: Effect of LHM application rate on graminoid ANPP on the CWG, MP, and FG sites in 1999.

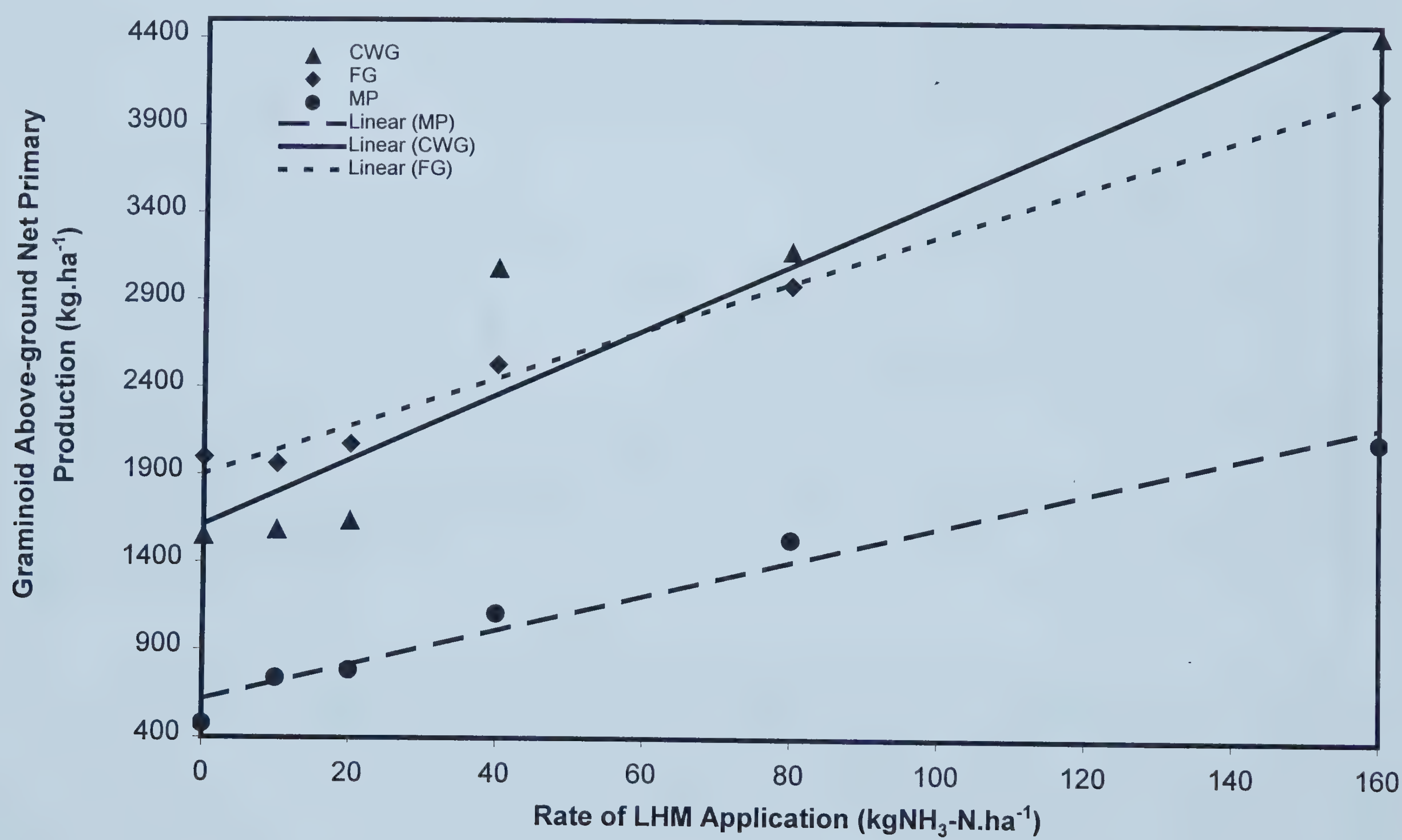


Figure 3.2: Effect of LHM application rate on 1999 graminoid and alfalfa ANPP on the MB site.

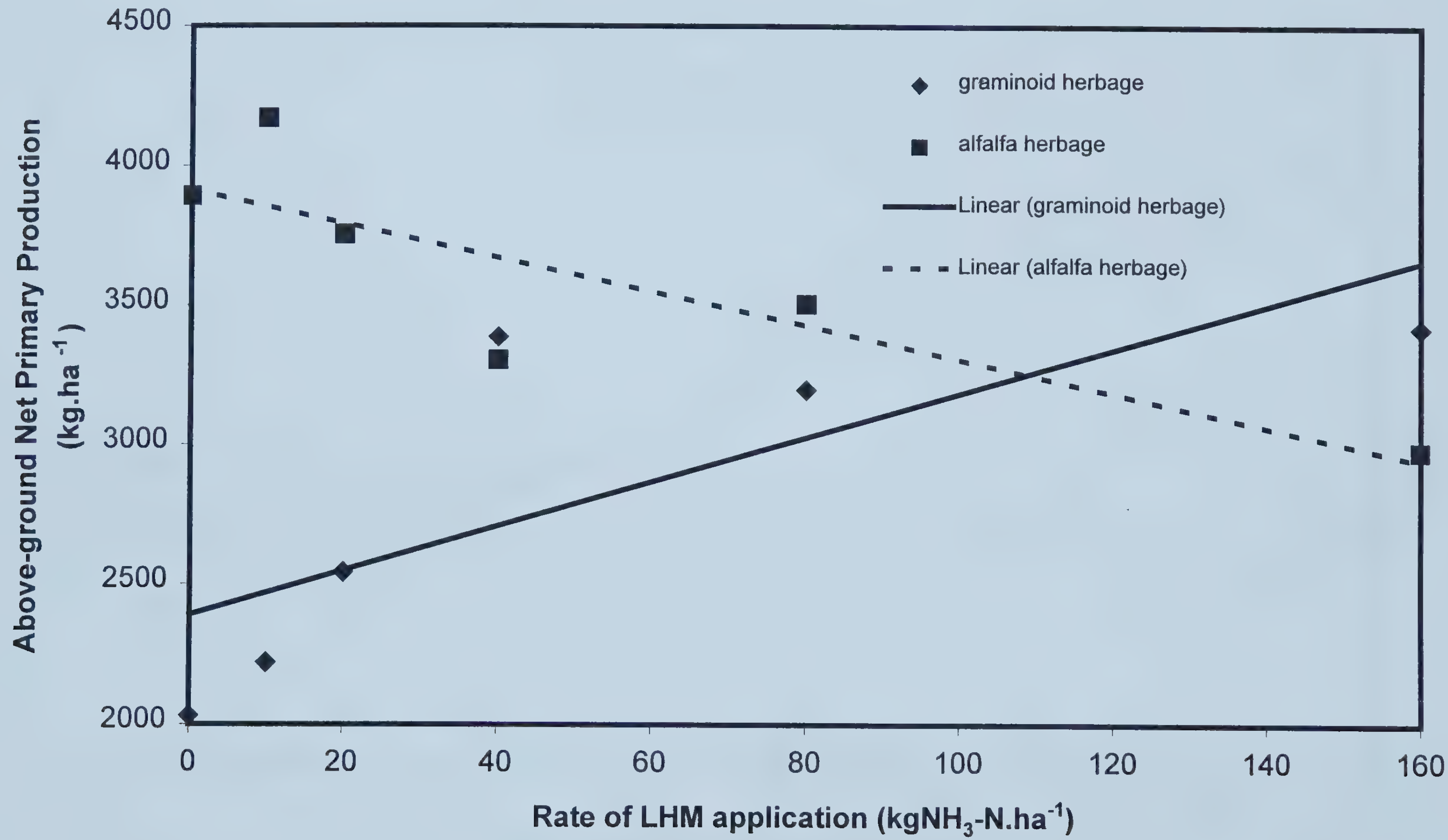


Figure 3.3: Effect of LHM application rate on forb ANPP on the MP site in 1999 and 2000.

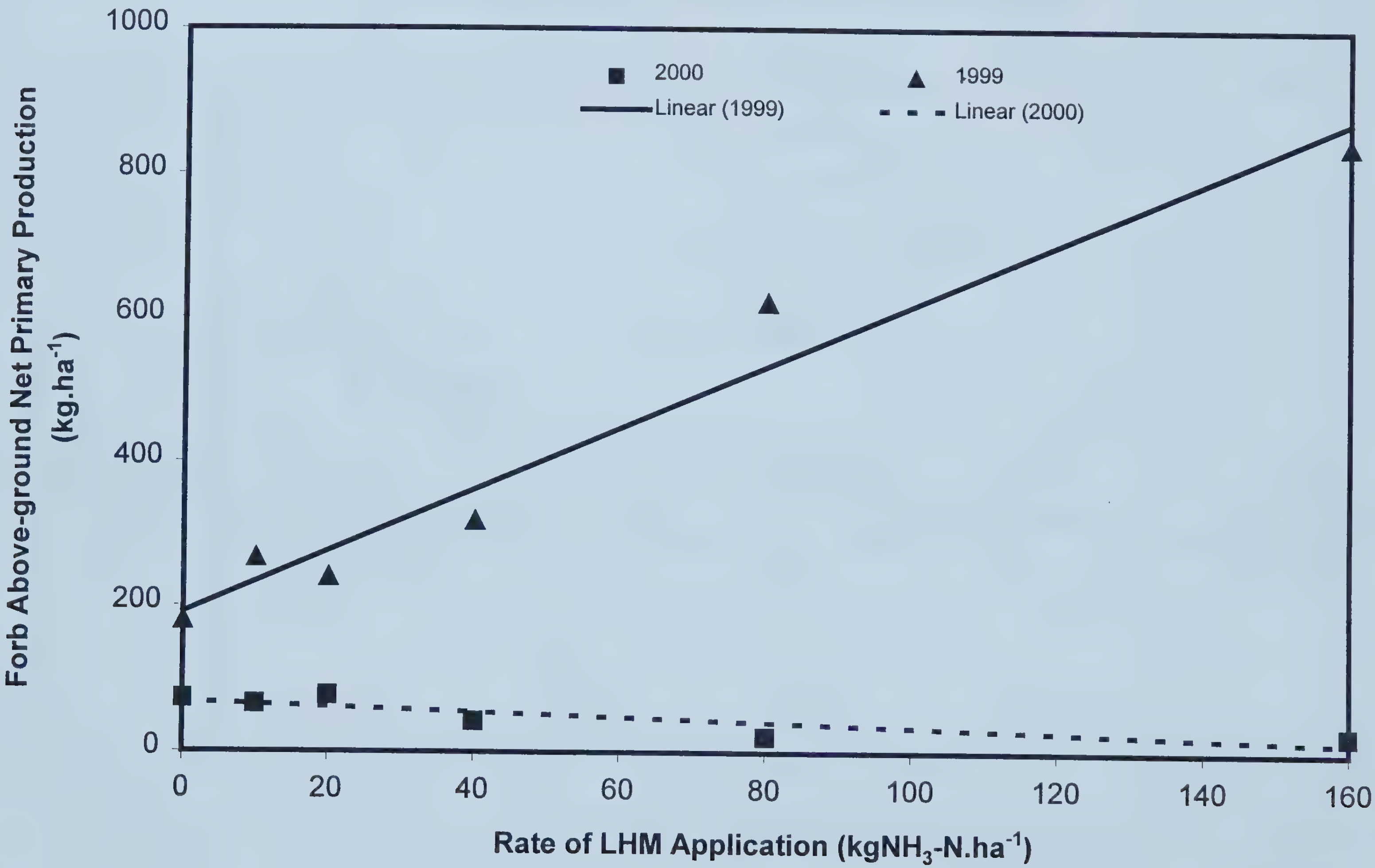


Figure 3.4: Effect of LHM application rate and season of treatment on alfalfa ANPP on the MB site in 2000.

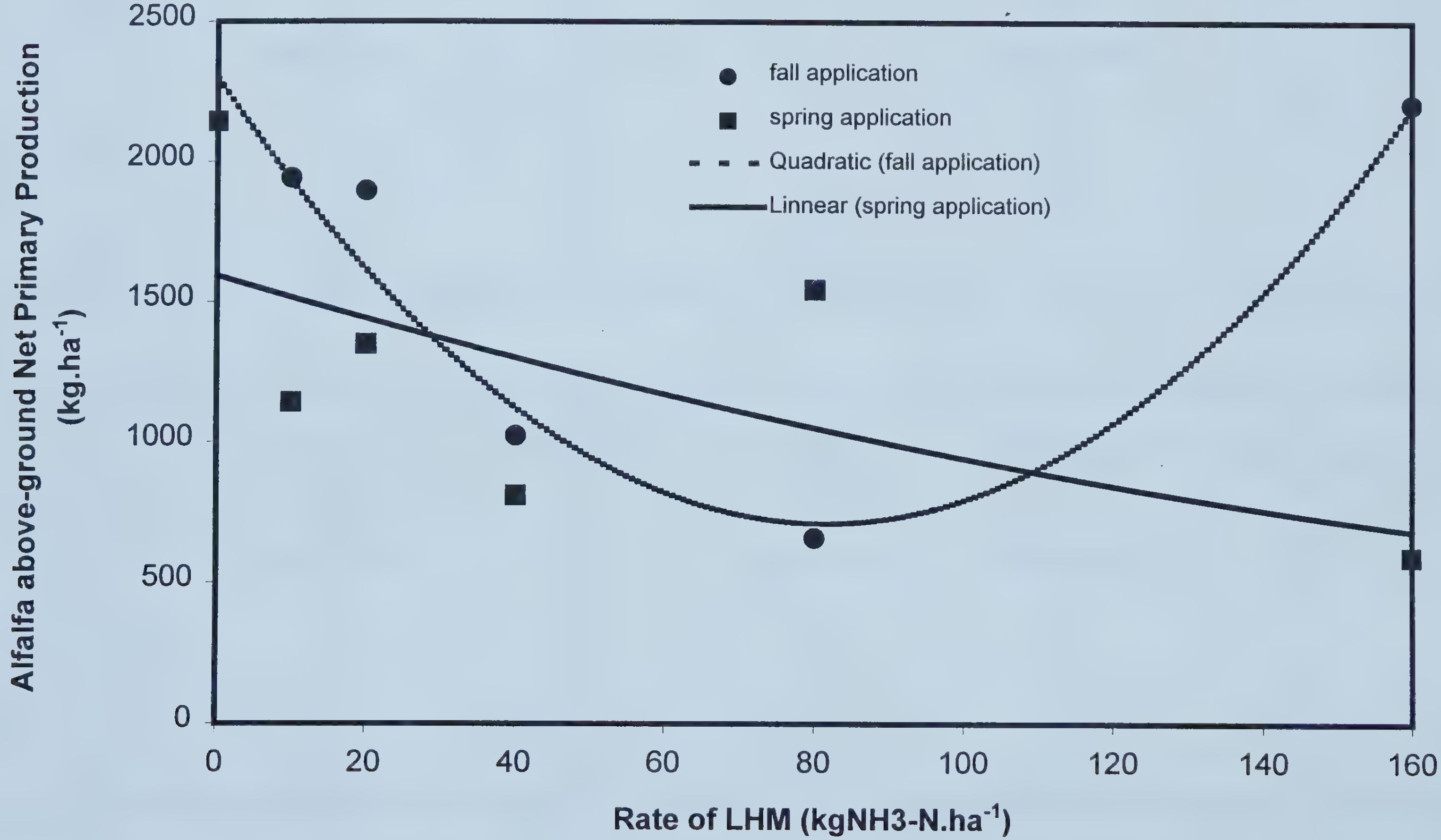


Table 3.5: Summary of significant forage quality responses on the Fescue Grassland and Crested Wheatgrass-Alfalfa sites in 1999.

Factor[1]	Fescue Grassland			Crested Wheatgrass-Alfalfa		
	Protein	**Phosphorus**	**ADF**	**Protein**	**Phosphorus**	**ADF**
Method	ns	ns	ns	ns	ns	ns
Season	ns	ns	ns	ns	ns	ns
LIN_rate	**significant**	ns	ns	**significant**	ns	ns
QUA_rate	ns	ns	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns	ns	ns
LIN3	ns	ns	ns	ns	ns	ns

[1]Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*time, FOR*meth, FOR*time, QUA3, CUB3, FOR3, and time*method

Table 3.6: Summary of significant forage quality responses on the Meadow Brome-Alfalfa site in 1999 and 2000.

Factor[1]	1999			2000		
	Protein	**Phosphorus**	**ADF**	**Protein**	**Phosphorus**	**ADF**
Method	ns	ns	ns	ns	ns	ns
Season	ns	ns	ns	ns	ns	ns
LIN_rate	**significant**	ns	**significant**	**significant**	ns	ns
QUA_rate	ns	ns	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns	ns	ns
LIN3	ns	ns	ns	ns	ns	ns

[1]Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*time, FOR*meth, FOR*time, QUA3, CUB3, FOR3, and time*method

Figure 3.5: Effect of LHM application rate on graminoid crude protein at the CWG, FG and MB sites in 1999.

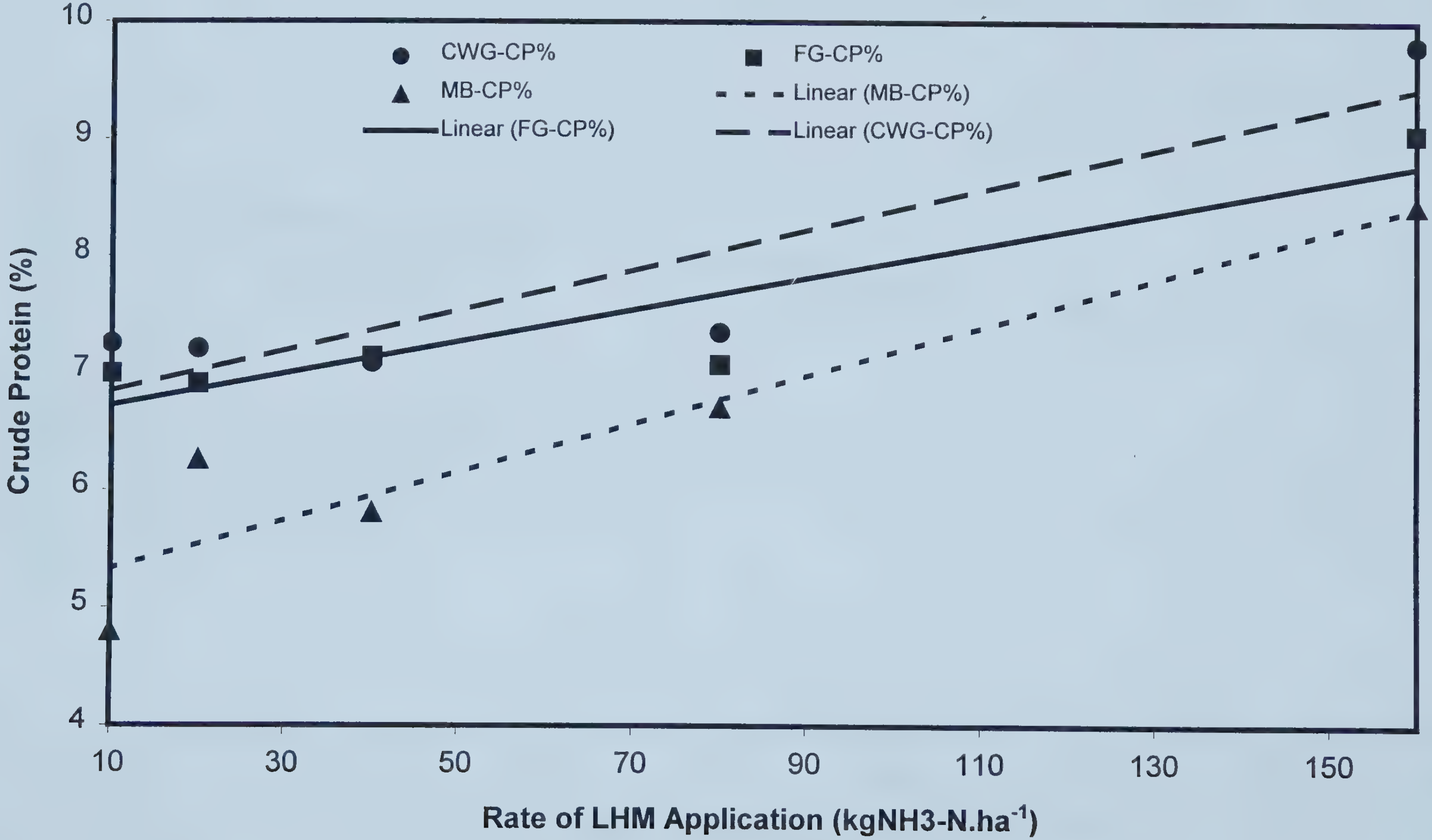


Figure 3.6: Effect of LHM application rate on graminoid acid detergent fiber on the MB site in 1999.

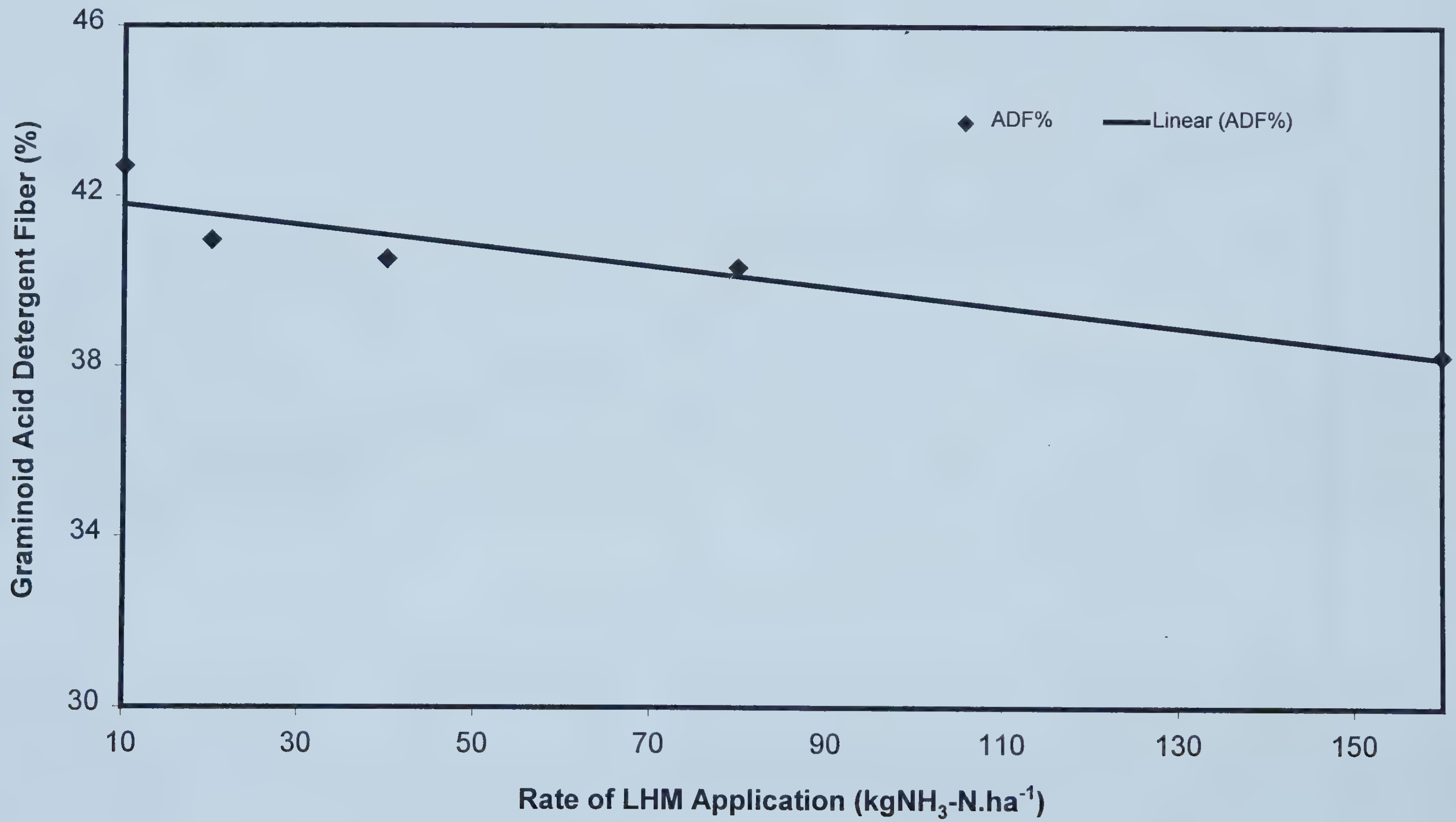


Figure 3.7: Effect of LHM application rate on residual grass crude protein on the MB site in 2000.

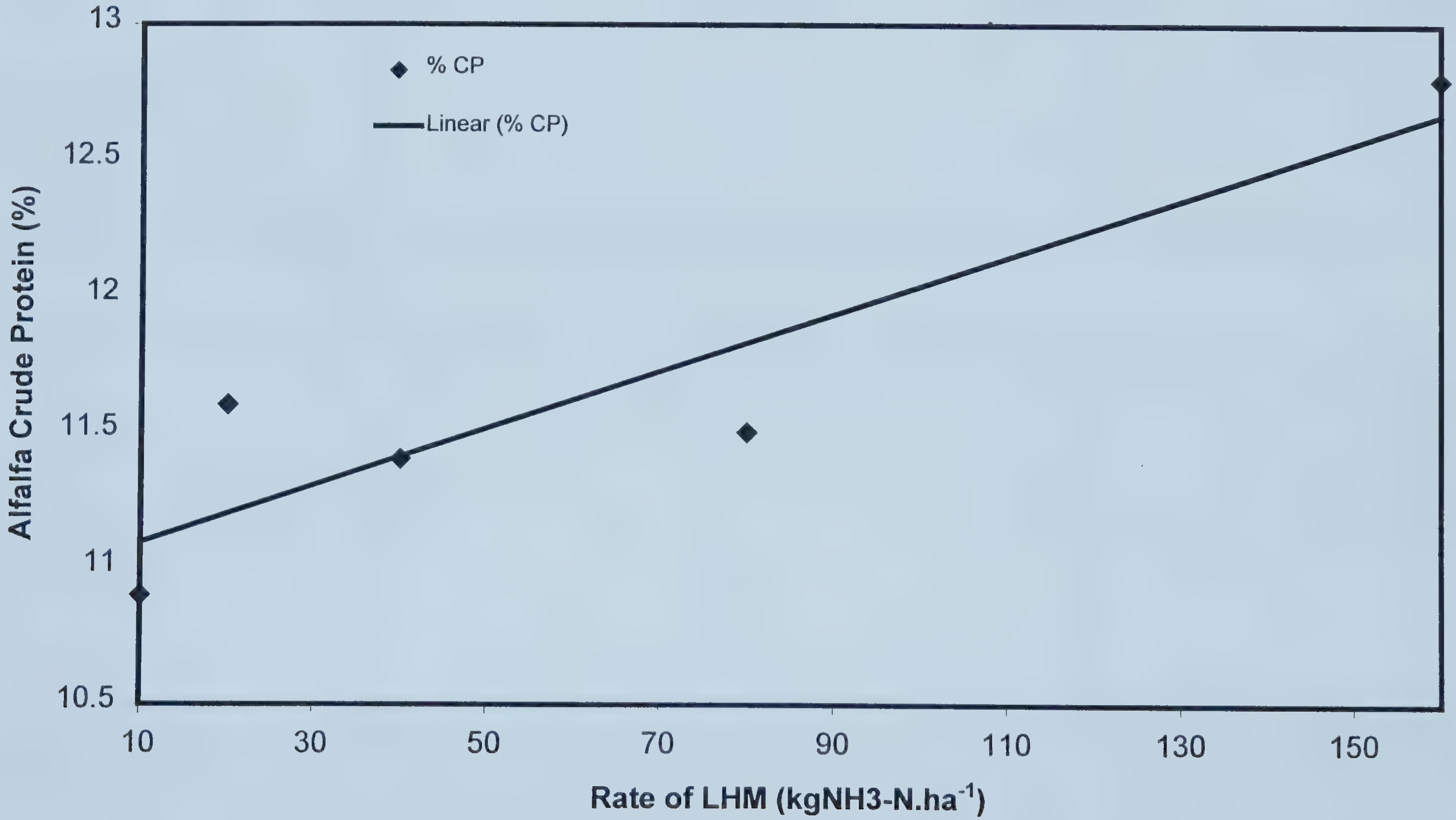


Table 3.7: Summary of significant grass crude protein yield responses across all sites in 1999.

Factor[1]	1999			
	Mixed Prairie	Fescue Grassland	Meadow Brome	Crested Wheatgrass
Method	ns	ns	ns	ns
Season	ns	ns	ns	ns
LIN_rate	**significant**	**significant**	**significant**	**significant**
QUA_rate	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns
LIN3	ns	ns	ns	ns

[1] Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*season, FOR*meth, FOR*season, QUA3, CUB3, FOR3, and season*method

Table 3.8: Summary of significant grass crude protein yield responses across all sites in 2000.

Factor[1]	2000			
	Mixed Prairie	Fescue Grassland	Meadow Brome	Crested Wheatgrass
Method	ns	ns	ns	ns
Season	ns	ns	ns	ns
LIN_rate	**significant**	ns	**significant**	**significant**
QUA_rate	ns	ns	ns	ns
LIN_rate*meth	ns	ns	ns	ns
LIN_rate*season	ns	ns	ns	ns
QUA_rate*meth	ns	ns	ns	ns
QUA_rate*season	ns	ns	ns	ns
LIN3	ns	ns	ns	ns

[1] Indicates other possible factor combinations examined for significance included CUB_rate, FOR_rate, CUB*meth, CUB*season, FOR*meth, FOR*season, QUA3, CUB3, FOR3, and season*method

Figure 3.8: Effect of LHM application rate on graminoid crude protein yield within each of the four plant communities investigated in 1999.

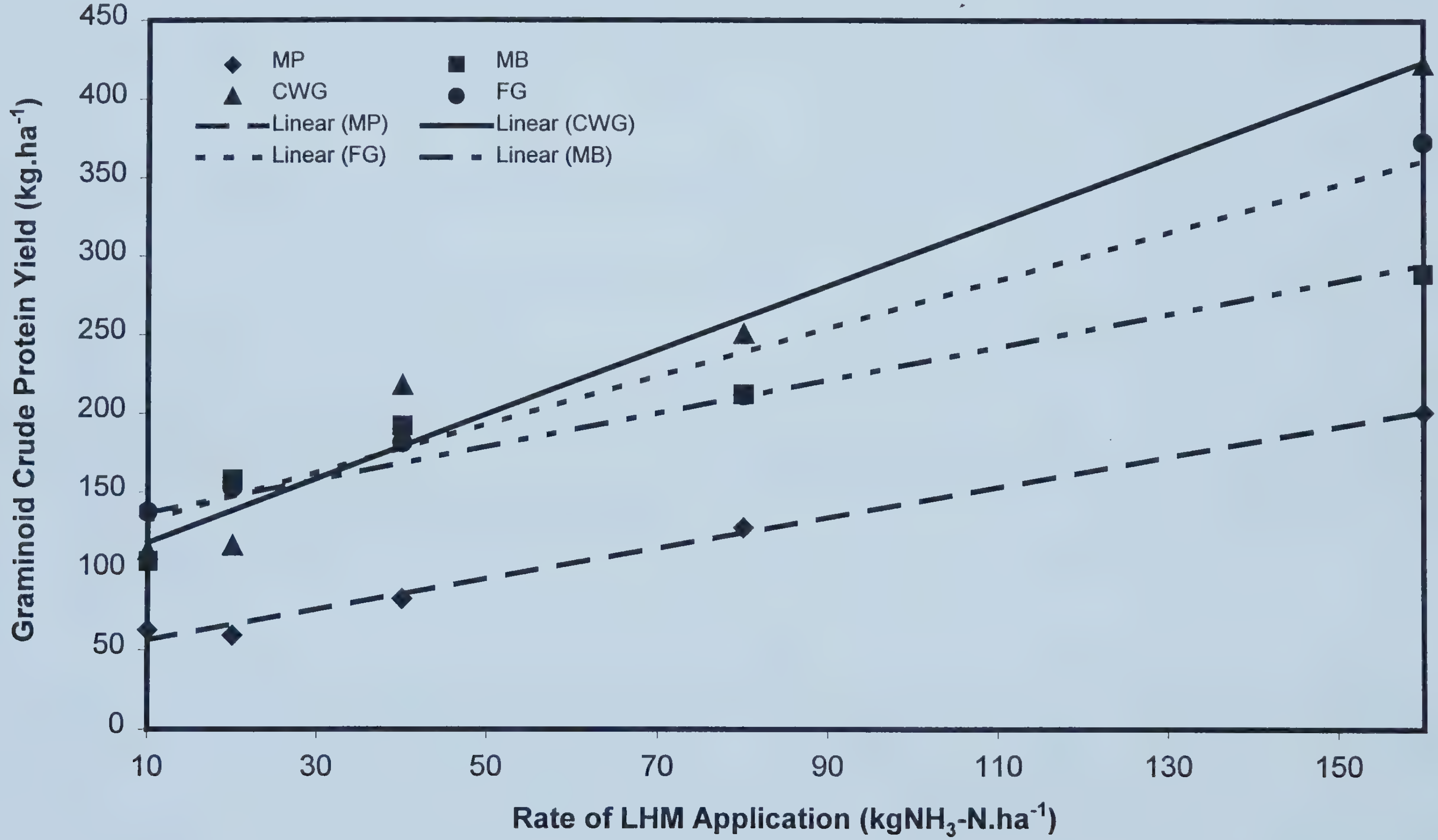
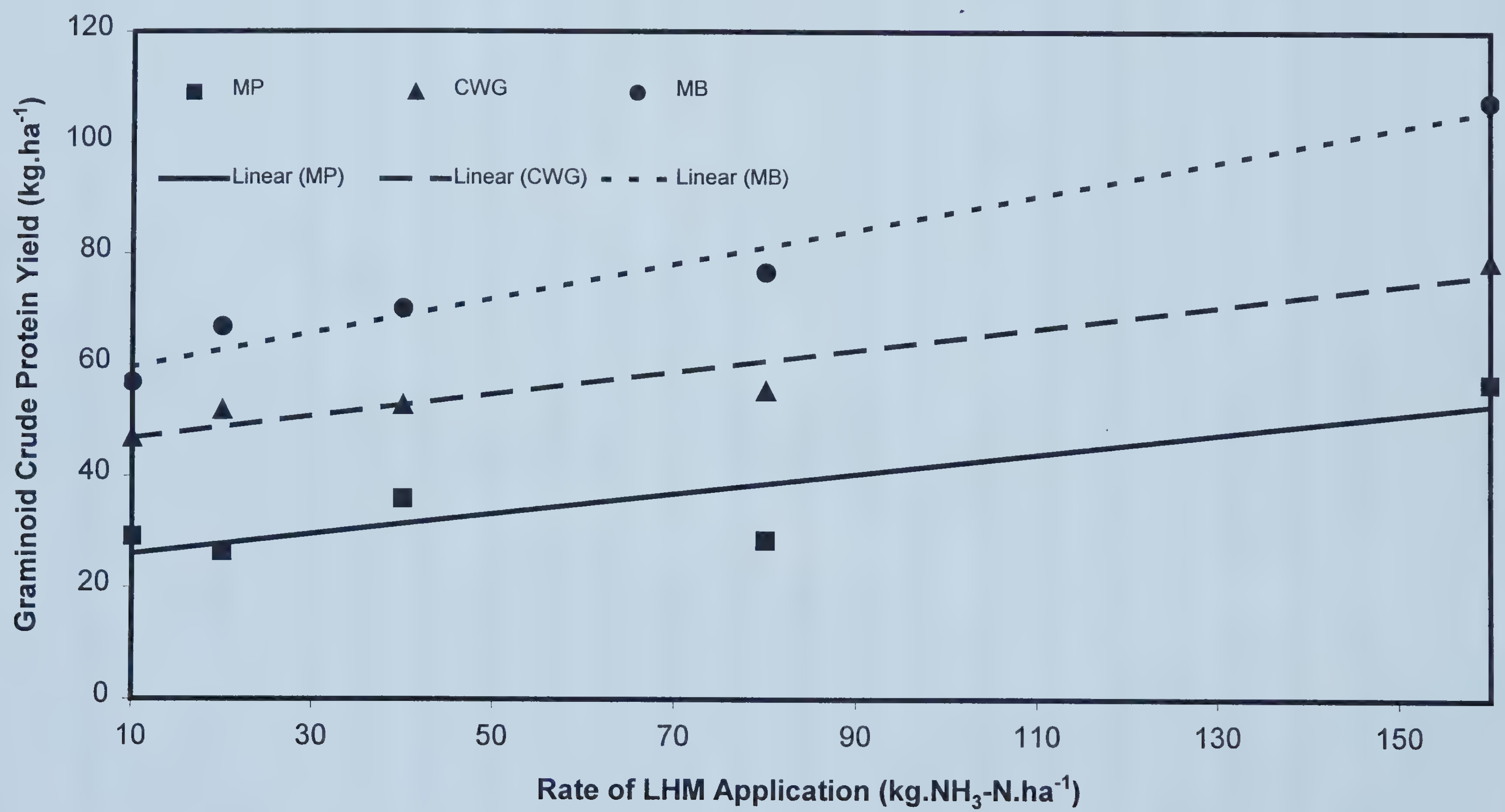


Figure 3.9: Effect of LHM application rate on residual graminoid crude protein yield within each of the four plant communities investigated in 2000.



Chapter Four

Plant Community Responses to One-Time Liquid Hog Manure Application

4.1 Introduction

Forage production on native rangeland and associated seeded pasture is of great interest to ranchers and land managers as it determines the potential for profitable livestock production. The forage production from plant communities, in turn, is largely determined by the dominant plant species present (Willms and Jefferson 1993), their vigour, and associated growing conditions (Rauzi 1978). As such, the effect of fertilization on herbage production within both native and tame communities has been relatively well documented (Bittman et al. 1997; Jacobsen et al. 1996; Johnston et al. 1967), with herbage production typically increasing with greater levels of nutrient addition. In contrast, far less research has examined botanical composition responses to nutrient addition, particularly on native plant communities.

In general, there is a relationship between nutrient supply and plant community composition in both native rangelands (Samuel and Hart 1998; Kalmbacher and Martin 1996) and tame pasture swards (Anderson et al. 1998; Bittman et al. 1997). Experimental evidence and field observations indicate that overall community diversity is prone to decline along an increasing nutrient (e.g., nitrogen) gradient (e.g., Wilson and Tilman 1993, 1991; Wilson and Shay 1990; Tilman 1982). However, changes in plant community composition and related declines in diversity may not be a sole result of nutrient availability. Plant community composition and dynamics are complex in nature, and as such, changes within the community following nutrient addition may be either direct (e.g., nutrient driven), indirect (driven by altered competition), or a combination of these (Pysek and Leps 1991).

On seeded swards, the addition of N in particular can change the relative proportion of

different growth forms. Notably, N additions have led to increases in the proportion of graminoids at the expense of leguminous forbs such as alfalfa (*Medicago sativa* L.) (Bittman et al. 1997; Russelle 1992; Nuttall et al. 1991; Dougherty and Rhykerd 1985). Similarly, in southern Alberta, solid beef and liquid hog manure applied at two different sites failed to affect the abundance of alfalfa regardless of manure type, application rate, or season of application (spring vs. fall) (AFMRC 1999).

Along with intrinsic changes in species composition, there is a risk that nutrient addition will facilitate invasion and establishment of weedy species into tame pastures. Short-lived, but rapidly growing nitrophilic species such as common pepperweed (e.g., *Lepidium densiflorum* Schrad.) and lamb's quarters (*Chenopodium album* L.) may be able to capture and utilize nutrients more effectively than long-lived desirable plant species (Haas and Streibig 1982; Houston and Hyder 1975). Kentucky bluegrass (*Poa pratensis* L.), an invasive perennial grass has been found to respond positively to N fertilization. Thompson and Clark (1993) found that increasing rates of N fertilization led to increases in both bluegrass seed head production and the number of large (>1.5 mm diameter) tillers when grown within growth chambers. Furthermore, nutrient addition may eliminate certain species increasing opportunities for colonization by invasive species such as smooth brome (Johnston et al. 1968).

Research has suggested that the impact of N application on weed establishment within tame forage swards and cereal crops is closely linked to the placement and timing of treatment (Anderson et al. 1998; DiTomaso 1995). For example, densities of green foxtail (*Setaria viridis* (L.)) were reduced within winter wheat when N was applied early in the growing season (Black and Siddoway 1977), allowing the crop to gain an early competitive advantage. Nitrogen addition may actually reduce weed densities due in large part, to increased cover crop competitiveness (Anderson et al. 1998; Pysek and Leps 1991). This trend is especially evident when low-growing, prostrate weed species are trying to compete with a taller, denser crop canopy (Pysek and Leps 1991).

Research on native rangelands suggests that nutrient addition may also alter community

composition, increasing the abundance of some plants while simultaneously decreasing the abundance of others. On Mixed Grass rangeland in Wyoming, nitrogen application increased the abundance of western wheatgrass (*Agropyron smithii* Rydb.) at the expense of blue gramma *(Bouteloua gracilis* (HBK) Lag.) and needleleaf sedge (*Carex filifolia* Nutt.) (Samuel and Hart 1998). This is in agreement with an earlier study (Rauzi 1978) that showed western wheatgrass increased and blue gramma decreased following N application on Shortgrass Prairie in Wyoming. Another investigation on Mixed Prairie found that *Koeleria macrantha* (Ledeb.) J.A. Schultes f., a common bunchgrass, was nearly eliminated at all rates of N application (Houston and Hyder 1975). Elimination of flora from a community must not be ignored, as it provides the opportunity by invasion of undesirable, weedy species (Johnston et al. 1968), and may contribute to a more homogenous plant community. It also may represent a general decline in biodiversity, which is an important desirable attribute of native rangeland (West 1993), particularly on public land.

An important ecological concern on native rangelands is the potential for changes in plant community diversity following nutrient addition. Changes in diversity represent alteration in richness (number of species) and evenness (relative distribution of species) within the community. Research on flatwood range in Florida showed a decline in plant diversity as N application rates increased (Kalmbacher and Martin 1996). Substantial research in the early and mid 1990s further demonstrated that community diversity declines on a nutrient gradient, generally resulting in fewer species in a nutrient-rich (e.g., amended) community relative to those that were nutrient-poor (e.g., untreated) (Wilson and Tilman 1993, 1991; Wilson and Shay 1990). Furthermore, a diverse mix of plant species is desirable because animals select for heterogeneous sites (Gesshe and Walton 1981), presumably to maximize opportunities for forage selection.

High application levels of either N or N + P have been found to increase the abundance of undesirable plant species on native range communities (Berg 1995; Houston and Hyder 1975; Goetz 1969; Johnston et al. 1967), including *Descurrania sophia* (L.) Webb, *Hordeum jubatum* L., *Agropyron*

repens (L.) Beauv., *Lepidium densiflorum* and *Artemisia frigida* Willd. The majority of research shows a positive relationship between weed abundance and nutrient application rate (Goetz 1969; Johnston et al. 1967). Furthermore, it appears that some undesirable plant species are adept at capitalizing on excess nutrient availability and generating an immediate (e.g., first-year response), while others are better adapted for long-term, residual responses to nutrient addition. For example, the density of fringed sage (*Artemisia frigida*), an unpalatable half-shrub, increases as a result of nutrient addition on some rangelands (Goetz 1969), although this response seems to be short-lived (e.g., during first year following application). In contrast, (Berg 1995) found a warm-season planting in Oklahoma failed to show significant weed responses in the year of nutrient application, but generated residual weed production responses one year later.

Data on the impact of either method or season of nutrient application on plant community composition is more limited. The few studies that have addressed this issue have mostly been on tame pastures. Although Olson and Papworth (1999) had concerns that manure injection would negatively affect tame pasture communities, this did not occur. The disturbance inherent to LHM application could encourage compositional changes by promoting competitive release of some species (Huston 1979).

Despite its potential to manipulate botanical composition of a plant community, timing of application (e.g., season) is a factor that is seldom addressed when applying nutrient amendments. Applying N fertilizers early in spring promotes cool-season species (Wolf et al. 1979). In contrast, warm-season species respond better to regular applications of N throughout the growing season (Whiteman 1980). Leguminous crops such as alfalfa, which may decline with increasing N application (Bittman et al. 1997; Dougherty and Rhykerd 1985), do not appear to respond to different seasons of nutrient application (Olson and Papworth 1999).

While data on the compositional response of plant communities to commercial fertilizers are relatively common, particularly on tame pastures, data indicating botanical composition changes to

either solid or liquid manure application are limited. Even less is known about the response of native rangelands to manure addition. Sustainable manure management is quickly becoming an important issue, as intensive livestock operations (ILOs) expand in number, size, and geographic distribution. In Alberta, hog-based ILOs are expanding into semi-arid regions of the province, an area that is often marginally productive and largely uncultivated.

Animal manure, an abundant by-product of ILOs, has historically been applied to cultivated lands to aid annual crop production. However, the transport of manure from established hog operations in south-central Alberta to cultivated lands is not always practical from either a logistical (time) or economic (transport cost) perspective. Instead, perennial forage lands in the vicinity may constitute the most practical sink for liquid hog manure (LHM) generated by these ILOs. Perennial forage lands include both native rangelands, which are more common in arid and semi-arid regions, as well as seeded tame pastures, which occur throughout more intensive agricultural regions of the province.

In order to safely and efficiently utilize forage lands in south-central Alberta as a sink for LHM, the plant community responses to this amendment must be understood. This includes the response of both important individual plant species as well as the overall community to various methods, rates, and seasons of LHM application. This information, gathered and assessed over both the short and long term, will help determine when (and where) LHM application is environmentally sustainable. Where LHM application to native range and seeded pasture is consistent with maintaining diverse, functional, and "healthy" (e.g., intact native) plant communities, practical guidelines need to be developed to establish appropriate manure application criteria on different types of native rangeland and tame pasture, including under both xeric and mesic moisture regimes. Specific objectives of this study were to (1) identify whether increasing rates of LHM application altered plant community composition, (2) evaluate plant community changes under both surface (dribble broadcast) and sub-surface (coulter injected) methods of LHM application, and (3)

determine plant community composition responses to both spring (e.g., April) and fall (e.g., October) LHM applications. A secondary objective was to contrast plant community composition and seed head production responses among different forage lands, including native rangelands and tame pastures, representing both xeric and mesic moisture regimes.

4.2 Methods

4.2.1 Study Sites

This research was conducted in south-central Alberta, near Little Fish Lake (51°22′ N, 112°13′ W) (Appendix A-I). The area is approximately equidistant from the municipal centers of Hanna (northeast) and Drumheller (southwest). Topography of the region is gently undulating with well-defined plateaus and valleys, at an average elevation of ~800m above sea level. Climate of the region is continental. Warm summers and cold winters typify the area, with a semi-arid mean annual precipitation of 394 mm. This long-term (30-year) average is a result of climatic data compiled from the nearest weather station at Craigmyle, Alberta, 30 kilometers north of the study area. Growing season precipitation (May to August inclusive) averages 217 mm. The mean annual temperature is 3.1 °C, with May to August temperatures averaging 10.3, 13.9, 16.1, and 14.8 °C, respectively (Environment Canada 1993). There is, however, a great deal of inter-annual variation in growing conditions.

Due to the variability in terrain and elevation, there are marked landscape-based differences in effective moisture regimes and resulting soils. Mesic areas have Dark Brown to Black Chernozems (Typic Haplustoll Series), whereas xeric sites are expressed as shallow, Brown Chernozemic soils (Aridic Haplustoll Series). In addition, the geographic location of the study area represents the juxtaposition of two distinct ecoregions: Mixedgrass Prairie and Aspen Parkland (Strong and Leggat 1992) (Appendix A-I), the latter of which includes northern fescue grasslands

(Coupland and Brayshaw 1953). Four unique study sites were examined, exemplifying the range of plant communities in the region, including native rangeland communities representative of the xeric Mixed Prairie (MP) and mesic Fescue Grassland (FG). Specific range types on the MP and FG sites are representative of the *Stipa-Agropyron* and *Festuca-Stipa* faciations, respectively (Coupland 1992a, 1992b). To contrast with these native rangeland communities, two introduced pastures were examined, including an Alfalfa (*Medicago sativa* L.) - Meadow Brome (*Bromus bierbersteinii* Roem & Schult)-Crested Wheatgrass [*Agropyron cristatum* (L.)] sward seeded in the spring of 1997 on a mesic Black Chernozem, the other a xeric Brown Chernozem with a stand of Crested Wheatgrass - Alfalfa - Russian Wild Rye (*Elymus junceus* Fisch.) established in ~1986. Pre-treatment soil characteristics and nutrient status are contained in Appendix B-I. The latter two sites will hereafter be referred to as the Meadow Brome (MB) and Crested Wheatgrass (CWG) sites, respectively.

All sites were selected in 1998, and chosen on the basis of their internal homogeneity of range site conditions and vegetation expression. Research sites were in good to excellent range condition (e.g., not overgrazed). Both of the native range communities were used for dormant season grazing from mid-October through mid-December of each year at low stocking rates with hay supplemented in December. From March 27th through April 30th of both 1999 and 2000, the CWG site was used as a calving pasture, and experienced higher stocking rates (e.g., ~4.0 AUM/ha). Only the MB site saw different management/grazing regimes between 1999 and 2000. In 1999, this pasture was hayed (excluding the study site), and subsequently grazed from September 15th through October 15th at a very low stocking rate. In 2000, this same area was grazed for 5.5 consecutive months at a stocking rate of 2.7 AUM/ha. It is important to note that for each of the four study sites, stocking rates were for the entire field and not the research site itself. Total field areas were 64.75 ha for the CWG site and 388.5 ha for each of the MB and winter field, the latter of which encompassed both the FG and MP sites.

4.2.2 Manure Treatments

Each research site (e.g., plant community) was equal in size (150*50m), and divided into 23 treatment plots, with each plot 7*50m. Treatments were designed to examine three unique characteristics of LHM application, including rate (10,20,40,80, and 160 kgNH_3-N.ha^{-1}), method (dribble broadcast vs. injection), and season (fall vs. spring). Twenty possible treatment combinations were randomly applied to each of the four plant communities. In addition to the treatment combinations, there were three controls at each site, two of which were dry passes of the injection equipment (one in the fall and one in the spring), and one of which was a true control (e.g., no treatment or machinery disturbance). Following completion of the manure treatments, each study site was fenced in late April 1999 to exclude livestock.

LHM was applied to study sites by means of the Greentrac slurry injection system, owned and operated by the Prairie Agricultural Machinery Institute (PAMI) in Humbolt, Saskatchewan. Half the LHM treatments were applied between October 5th and 7th, 1998, with the remainder applied April 12th and 14th, 1999. Coulters on the Greentrac were at a 25 cm spacing and each plot had a half meter buffer on every side. Where LHM was injected into the soil, injection was to a maximum depth of 10 cm, but ranged between 7.5 and 10 cm. Surface applications were made using the same machinery, with adjustments made so LHM was dribbled onto the ground surface from a height of ~30 cm. In this respect, Greentrac broadcast treatments were different than traditional splash-plate application technology in terms of liquid manure atomization and susceptibility to atmospheric drift.

In order to ensure LHM treatments were as consistent as possible, LHM samples were taken from the storage lagoon and analyzed for nutrient content two weeks prior to each application date for both the spring and fall treatments. Using this information, the Greentrac applicator was calibrated and tractor speed adjusted accordingly. Additionally, each load of LHM during the

treatment application phase was sampled and subsequently tested for nutrient content to ensure consistency among loads. Manure nutrient data is presented in Appendix B-I. Despite intensive testing and calibration, actual application rates were slightly lower (~5%) than target application rates. This subtle discrepancy is likely an artifact of either changes in manure nutrient content between the time of sampling and treatment, or possibly nutrient differentials related to the location of manure extraction from within the storage lagoon. Theoretical and actual (adjusted) rates for both the spring and fall applications are presented in Table 4.1, along with the water depth equivalents for each treatment.

4.2.3 Vegetation Sampling

Community composition by canopy cover (to the nearest %) was determined for each plot at each of the 4 study sites, using $0.1m^2$ Daubenmire quadrats spaced along a randomly located transect. Minimum sample areas were determined for each of the 4 sites via preliminary surveys in mid-June 1999. These surveys were used to plot species abundance with incremental increases in sample area, with the minimum sample area deemed to be that above which average abundance (%) stabilized (Appendix B-II). More biologically diverse sites (e.g., native rangelands) required larger sample areas relative to less diverse areas (e.g., tame pastures) to accurately capture the number and abundance of plant species. Preliminary surveys indicated that minimum sample areas needed to stabilize cover values were 2 m^2 (20 frames), 1.5 m^2 (15 frames), and 1 m^2 (10 frames) for Mixed Prairie, Fescue Grassland, and the 2 tame pastures, respectively (Appendix B-II).

Species cover assessments on each of the 4 plant communities were conducted at peak vegetative growth during the successive growing seasons of 1999 and 2000. Community composition was determined from June 21st through June 24th, 1999, and June 29th through July 8th, 2000 on the seeded sites, while native vegetation, which is slower to commence active growth and reach maturity, was sampled from July 26th through August 11th, 1999, and August 2nd through

August 18th, 2000. All cover values were recorded to the nearest percent, rather than in cover classes. Total species richness and diversity (using the Shannon-Wiener index) were determined for each plot to assess overall community level responses to the LHM treatments. Intraspecific responses were then examined at each of the four plant communities. To facilitate intraspecific analysis, composition data was reduced to functional groups or dominant species and subsequently analyzed for trends.

On the CWG pasture, the composition of each perennial grass (crested wheatgrass & Russian wildrye), alfalfa, and "other species" (primarily weedy forbs) were each analyzed. On the MB pasture, alfalfa, meadow brome, crested wheatgrass and other species (primarily weeds) were analyzed. Due to the greater plant diversity within native rangelands, both the MP and FG sites were analyzed for composition trends by plant functional group. On the FG site, compositional cover data were grouped (e.g., summed) and analyzed for perennial grasses, *Carex* spp. (e.g., upland sedges), and dicots (all forbs & shrubs). The more xeric MP site was analyzed by the groupings of bunchgrasses, rhizomatous grasses, *Carex* spp., and dicots (all forb & shrubs). Functional groups were analyzed rather than individual species for two reasons. First, it is more practical to analyze functional groups, especially on sites that have numerous species such as the two native rangelands. Second, functional group analysis is based on the premise that species with similar morphological or growth characteristics have similar responses to treatment. As such, functional group analysis provides a mode of discerning whether or not one group of similarly behaving species is having a sizable effect on identifiable ecosystem characteristics (e.g., composition or yield, for example) and their related processes (Hooper and Vitousek 1997).

Seedhead production was also analyzed for the dominant grass species on each of the 4 sites in both 1999 and 2000. Seedhead production was assessed in order to gain a perspective on longer-term changes that could/may occur within the plant community. Dominant grass species were determined to be plains rough fescue (*Festuca hallii* (Vassey) Piper.) on the FG site, and *Stipa* spp.

(e.g., speargrasses), junegrass (*Koeleria macrantha)* and *Agropyron* spp. (e.g., wheatgrasses) on the MP site. On the tame pastures, dominants included crested wheatgrass on the CWG pasture, and both crested wheatgrass and meadow brome on the MB pasture. Seedhead production was assessed using 4 randomly placed 0.5m^2 quadrats on each plot, and counts were carried out in concert with annual net primary production (ANPP) clips (Chapter 3).

4.2.4 Analysis

The fundamental experimental design of this research was a randomized block with four sites as replicates. Analysis using this design would have facilitated testing of main treatment effects, but precluded evaluation of site-based differences, as each site contained unreplicated multi-factor treatment combinations. Because of this restriction and the interest in identifying differential treatment effects between sites, particularly native rangelands and tame pastures, the application of traditional statistical analyses (e.g., ANOVA) was considered less suitable. Instead, an alternate procedure was used that employed trend analysis and partitioning of variance from each multi-factor treatment combination through a series of orthogonal contrasts using Proc IML within SAS™. Half-normal plots were subsequently employed to determine which main factor or factor combination(s), if any, were significant (Miliken and Johnson 1989). Due to the lack of replication within each plant community, significance levels were not distinguished in terms of p-values, but rather interpreted based on their relative distribution to one another within the half normal plot. Significant treatment effects were then expressed graphically using trend analysis. A complete example of the use of Proc IML and half-normal plots is located in Appendix C.

4.3 Results and Discussion

4.3.1 Growing Season Conditions

Growing season conditions in 1999 were favorable for plant growth, with precipitation

across the study area from May 27th to August 24th, 1999, totaling 284 mm (averaged over all four sites). This value is above the long-term (30-year) average from climatic data records at Craigmyle, Alberta, which indicate a mean precipitation for May to August inclusive at 219 mm (Environment Canada 1993). Given that the 284 mm represents a conservative estimate tempered by evaporative losses and the lack of data for the early part of May, a time when active growth is vigorous, 1999 represented a relatively mesic growing season, ~ 30% greater than the long-term regional average.

Dry conditions prevailed in 2000 and precipitation from May 3rd through August 15th totaled 106 mm (averaged over all 4 study sites). Although this total represents a conservative estimate for growing season precipitation, 2000 was clearly below the long-term normal (e.g., -40-50%).

4.3.2 Community Diversity and Richness

Community diversity & richness responses were limited in both years of this research. Means and standard deviations for all treatments factors, across each of the four study sites in both 1999 and 2000 are presented in Appendix E-I.

4.3.2.1 Season of LHM Application

Timing of LHM application did not generate any significant responses in terms of either plant community richness or overall diversity. This suggests that the timing of LHM (e.g., fall vs. spring) has no effect on community diversity and/or richness, provided vegetation is relatively dormant at the time of application.

4.3.2.2 Rate of LHM Application

Nutrient addition has been shown to reduce both community diversity and richness (Samuel and Hart 1998; Kalmbacher and Martin 1996; Wilson and Tilman 1993). The potential for declining diversity and richness is a concern, especially within native plant communities where biodiversity is

often a desirable characteristic to maintain (West 1993). Despite this concern, however, accelerating rates of LHM application failed to generate a consistent diversity or richness response in either year of data collection. In 1999, the first growing season following LHM application, none of the study sites showed a significant relationship between either diversity or richness and LHM rate. This was repeated in 2000, with the exception of overall community diversity on the FG and CWG sites. On these two plant communities, there was a residual trend of declining diversity (CWG site) and increasing diversity (FG site) with increasing LHM. Diversity on the FG and CWG sites were 0.595 and 0.234 at 10 $kg.ha^{-1}$ N while changing to 0.744 and 0.063 at 160 $kg.ha^{-1}$ N, respectively. However, neither trend was considered strong enough in the half normal analysis to be deemed statistically significant. Furthermore, within the seeded CWG pasture, declining diversity was not considered a major concern, particularly if the diversity loss was due to a reduction of undesirable species (e.g., weedy annuals).

Although overall richness and diversity indices changed little even at high rates of LHM application, further research and monitoring is recommended to fully quantify the relationship between these characteristics and increasing LHM application rates. This is particularly true in case limited sample sizes account for the lack of significant differences observed. The ability of a plant community to resist such changes may be tempered by a combination of factors including: 1) history of past use, 2) climate and weather, and 3) genetic potential.

4.3.2.3. Method of LHM Application

No significant responses in terms of either diversity or richness were generated by different methods of LHM application, suggesting there is no advantage to using one application methodology over the other (e.g., injection vs. broadcast). Disturbance (e.g., annual tillage) has been found, for example, to alter competition intensity within plant communities (Wilson and Tilman 1993), with competition intensity decreasing with disturbance. This finding could precipitate

changes in either community diversity or richness. Despite the lack of significant diversity and richness responses to method of LHM application within this study, further research should be initiated to more fully quantify and verify the responses found here, particularly over the long-term.

4.3.3 Vegetational Composition

Overall community composition responses to different seasons, rates, and methods of LHM application are presented in Tables 4.2 and 4.3. Mean plant community composition and standard deviations for all treatments in both years of the study are presented in Appendix E-II.

4.3.3.1 Season of LHM Application

Season of LHM application generally had little effect on the abundance of cover components in either 1999 or 2000 (Tables 4.2 and 4.3). The one exception to this was the MP community, where bunchgrass cover showed a significant response to the interaction of rate(quadratic) and season of application (Table 4.3). Nevertheless, the general lack of responses among seasons suggests that LHM application either in early spring (e.g., April) or fall (e.g., October) will have a similar impact on the resulting plant community the following year. It is important to note that both seasons of application examined within this study were alike in that they occurred prior to active (e.g., photosynthetic) growth during the dormant period. Although other studies have shown that dormant season application is more advantageous for plant growth than application during the growing season (e.g., Wilkeen et al. 1989), this possibility was not tested here.

4.3.3.2 Rate of LHM Application

Immediate plant community composition responses in 1999 to various rates of LHM application were limited to the MB pasture (Table 4.2). On this site, both the rate of LHM application and the interaction of season, method and rate of LHM application significantly altered

the cover of crested wheatgrass. Crested wheatgrass cover response to increasing rates of LHM was determined to be linear (Figure 4.1), with the lowest rate of application generating an average cover value of 3.9% (+/- 0.80) while the highest rate generated average cover values around 7.7% (+/- 4.0). Although the cover of crested wheatgrass on the xeric CWG site also showed a linear response trend to accelerating rates of LHM application (Figure 4.1), and was characterized by crested wheatgrass cover increasing from 49.4% (+/- 4.4) to 66% (+/- 9.0), this trend could not be considered statistically significant according to the half normal analysis. The positive response of this particular tame bunchgrass suggests this species may exhibit superior capture of nutrients relative to other seeded forage plants with increasing LHM application, including alfalfa and meadow brome, neither of which changed in canopy cover within this study.

The ability of crested wheatgrass to initiate growth early in the spring may give it a competitive advantage compared to other forage grasses if fertilizer N is applied prior to active growth (Black 1968). Other research has suggested that crested wheatgrass may respond better than other forages to N fertilizer under pasture or hay management regimes (McCaughey and Simons 1996), while other species (e.g., smooth brome) with higher regrowth potentials are able to provide more uniform production over the duration of the growing season under N fertilization. It appears that little research has been conducted examining the response of crested wheatgrass to N fertilization in pasture mixes, especially relative to other common forage grasses. As such, further research on this would be useful for pasture managers to further evaluate these results.

Residual cover responses to LHM application rate were limited in 2000, occurring only on the MP site (Table 4.3). Although no first year effects were observed on this site in 1999, the cover composition of 'Other' vegetation (e.g., perennial and annual forbs) was significantly affected by LHM application the year before. This response was linear, with forb cover decreasing with increases in LHM application 18 months before (Figure 4.2). This decrease in forb cover may be caused in part by inter-specific competition between graminoid and forb components, including

competition for limited moisture, nutrients, and space. Wilson and Tilman (1991) suggest that competition occurs along a nutrient gradient, with competition among vegetational components being most intense at high rates of N. It is possible that competition between the forb and grass fractions of this Mixed Prairie community intensified following greater applications of LHM, which would then have been compounded by low precipitation in 2000. Most dicotyledonous plants (e.g., forbs) have taproots that spread laterally. In contrast, most graminoids have an extensive fibrous root system (Brown 1995). This morphological difference between growth forms may influence competition intensity, especially in xeric years (e.g., 2000), as grasses would (generally) be better equipped to capture moisture at greater depths.

Increasing rates of LHM could increase the abundance of unpalatable plants or invasive weeds (e.g., Anderson et al. 1998; Haas and Streibig 1982; Houston and Hyder 1975; Cosper et al. 1967). Within the xeric MP, the canopy cover of pasture sage (*Artemisia frigida*) nearly doubled (increasing from 9 to 16%) in 1999 as the rate of LHM application increased. This increase parallels an increase in weedy annual phytomass on the MB pasture in 1999 from 23 to 58 $kg.ha^{-1}$ with increasing rates of LHM application (see Chapter 3). In both of the above cases, however, the response of undesirable/weedy species was not large enough to elicit a statistically significant response. No residual responses were apparent in the abundance of undesirable or unpalatable species on any of the study sites in 2000.

The FP site did not show any vegetational response to LHM application rate, possibly due to the high vegetation cover values already at this location. The FP site is situated within a mesic topographic position with favorable moisture conditions. As such, the vegetation here is expressed as a well-developed canopy of taller grasses (e.g., fescue and speargrasses), which are proficient at maintaining high densities, curbing competitive release of undesirable species, and generally resisting changes in community composition. Site conditions are more favorable at this location, with higher levels of both soil water and organic matter, suggesting that any addition of LHM may be less

proficient at increasing the cover of dominant species, because they are already near their maximum potential. Detailed site data (e.g., pre-treatment soil characteristics) is presented in Appendix B-1.

4.3.3.3 Method of LHM Application

No direct significant differences between the two methods of LHM application (sub-surface injection and dribble broadcast) were found on any of the four research sites. However, the interaction of rate (linear), season and method did generate significant responses in 1999 with respect to bunchgrass and crested wheatgrass cover on the MP and CWG sites, respectively (Tables 4.2 and 4.3). Despite this, the results (or lack thereof) strongly suggest that the process of coulter injection, by minimizing disturbances of the soil and vegetation, had little impact on the vegetational cover of permanent forage stands, either tame pasture or native rangelands. Low levels of soil disturbance were noted (data not shown), with soil sealing and vegetation recovery occurring rapidly enough to minimize the apparent invasion of weeds or other undesirable species. Recovery may also have been aided by the high precipitation in 1999, as drought the year following disturbance could have caused an added stress leading to a reduction in some species. Nevertheless, these results suggest low disturbance injection technology is compatible with maintaining tame pasture and native rangeland composition.

4.3.4 Seed Head Production

Seed head production was measured to monitor changes in reproductive physiology and detect potential future species compositional changes within each plant community. Seed head production responses to the season, rate, and method of LHM application are presented in Tables 4.4 and 4.5. Mean seed head production and standard deviations in both years of data collection are presented in Appendix E-III.

4.3.4.1 Season of LHM Application

Seed head production showed few significant responses to different seasons of LHM application. The overall lack of responses among dependant variables (e.g., seed head production of different species) to different seasons of LHM application suggests that any differences between spring (e.g., April) and fall (e.g., October) applied treatments are negligible. Other trials involving nutrient addition have generated results suggesting that the most beneficial time to apply manure is prior to active growth (Campbell et al. 1986).

4.3.4.2 Rate of LHM Application

Seed head production in 1999 was largely unaffected by the rate of LHM applied the previous dormant season. Relevant literature (e.g., Houston and Hyder 1975; Johnston et al. 1967) has suggested that rhizomatous species (e.g., wheatgrasses) are well adapted to capitalizing on nutrient additions. In agreement with these findings, the number of wheatgrass seed heads increased linearly with accelerating rate of LHM application from 26 to 32 per $0.5m^2$. However, this response was short-lived and did not translate into a longer-term (e.g., residual) trend.

In 2000, the rate of LHM application significantly affected the production of plains rough fescue seed heads on the FG site (Table 4.5). Seed head production of fescue increased linearly with accelerating rates of LHM application (Table 4.5) from 32 to 70 per $0.5m^2$. While a literature review failed to locate corroborating evidence for this result, rough fescue has been shown to respond positively to other stimuli, including fire, litter removal and timing of defoliation, with a one year delay commonly preceding the response (Bork et al. 2000; Willlms 1991; Willms et al. 1986).

In contrast to rough fescue, junegrass seedhead production on MP was affected in 2000 by the interaction of LHM application rate (quadratic) and season of application (Table 4.4, Figure 4.3). While there is a chance that this is a spurious effect given that neither method nor rate of application had an effect on this variable in 1999, the quadratic nature of the relationship may also

indicate complex tradeoffs in inter-specific competition between plant species within the MP community at different rates of LHM. The differential responses between seasons of application could be linked to variable sensitivities of junegrass to increased nitrogen, including the available form of nitrogen. A greater proportion of available N at the start of the growing season in 1999 on the fall-applied treatments consisted of nitrate (data not shown), as nitrification occurred throughout the winter of manure-applied ammonia the previous October. This in turn, may have affected meristematic development in 1999 and subsequent seedhead production observed in 2000.

Interestingly, the MP site also exhibited a trend of declining *Stipa* seedhead production with increasing rates of LHM application in 2000 (data not shown), but was not considered statistically significant. In contrast, seedheads of meadow brome were virtually absent in 2000 on the MB site. Although this particular bunchgrass was present in both years of the study, seedhead production was limited to 1999. The lack of any differences in 1999 suggests this observed year-to-year variation is due to variable precipitation rather than LHM application 2 years previous.

4.3.4.3 Method of LHM Application

No significant responses in seed head production to the two methods of LHM application were evident in 1999 or 2000. This result again suggests that single pass coulter injection of LHM does not negatively impact seedhead production from forage lands, and thus, their long-term sustainability. Consequently, injection of LHM into the soil may be a viable option for land managers, especially if there is interest in reducing ammonia losses to the atmosphere and managing odor emissions. More research is needed to quantify the impacts (both direct & indirect) of different methods of LHM application, including repeated manure applications. Although coulter injection is a low disturbance technique, repeated through time these disturbances may create additive effects within the plant community, particularly on native rangelands.

4.4 Conclusions

This study indicates that forage lands, including sites representative of native rangelands and seeded pastures, exhibit a substantial capacity to resist changes in plant species composition following nutrient addition through LHM application.

All four of the study sites examined had low levels of overall change in floristic composition, including species diversity and richness, even at high rates of LHM. Where changes did occur within the plant communities, increasing rates of LHM application were found to be the most frequent cause. This suggests that rate of LHM application is a relatively more important factor to consider than either season or method of application in terms of the ecological consequences to plant communities. Based on the results of this research, it appears that conservative LHM application rates (up to 40 $kg.ha^{-1}$) can be safely recommended as a one-time treatment without compromising range condition or ecosystem sustainability. Although higher applications maybe acceptable, they should likely be avoided until the long-term effects and role of climate and environment are better understood.

Both the season and method of LHM application should also be considered in terms of LHM disposal on forage lands as additional benefits may exist to their use. Similarly, moisture regime, site conditions, growing season conditions, and management regime will inevitably help determine the appropriateness of nutrient application to various forage lands, as will the current condition of a rangeland or pasture community. Given the year-to-year variation in growing conditions in this study and the potential link of vegetational responses with growing conditions, this study should be repeated in more years and on more sites to ensure that the responses found here will be maintained over time. In the interim, care must be taken to conservatively apply nutrients on forage lands, and to take site-specific characteristics into consideration.

Future research utilizing LHM also needs to more closely monitor community composition in association with traditional land use practices (e.g., grazing). It is clearly unrealistic to apply the results from this research without taking into consideration what (normal) grazing practices coupled with LHM application will do to plant community composition. Given that other research has suggested that nutrient application alters herbivore preference and selectivity (Samuel and Hart 1980), future trials need to be cognizant of and monitor for changes in botanical composition driven by the duel forces of nutrient availability and herbivore selectivity.

Significant changes in species diversity, plant community composition, and the abundance of seed heads were minimal on all four of the plant communities examined in this study. Despite the overall lack of significant changes, subtle changes in community character may not be detected through the half-normal statistical tests employed here. That is, seemingly minor changes within the plant communities due to main effects (e.g., season, method and/or rate of LHM application) should not be ignored, and indeed should be monitored over longer time frames. Changes in relative species abundance and increases in weedy species are possibilities when applying manure to forage lands, and researchers and land managers need to be cognizant of these issues.

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Table 4.1: Target and actual LHM application rates and associated water depth equivalents for both spring and fall seasons.

	Season of Application			
	Spring		Fall	
Target Application Rate ($kgNH_3$-$N.ha^{-1}$)	Actual Application Rate ($kgNH_3$-$N.ha^{-1}$)	Water Depth Equivalent (mm)[1]	Actual Application Rate ($kgNH_3$-$N.ha^{-1}$)	Water Depth Equivalent (mm)[1]
10	9.5	1.1	9.3	1.3
20	19.0	1.1	18.6	1.3
40	37.9	2.1	37.1	2.7
80	75.8	4.2	74.2	5.3
160	151.6	8.4	148.4	10.7

[1] Water depth equivalents for the application rates of 10 and 20 $kgNH_3$-$N\cdot ha^{-1}$ are the same because application rates involved LHM and ½ LHM + ½ water (dilution factor) for 20 and 10 application rates, respectively.

Table 4.2: Summary of significant canopy cover responses within the Meadow Brome-Alfalfa pasture in 1999.

Factor[1]	1999			
	Crested Wheatgrass	Meadow Brome	Alfalfa	Other
Method	ns	ns	ns	ns
Season	ns	ns	ns	ns
Rate_LIN	Significant	ns	ns	ns
Rate_QUA	ns	ns	ns	ns
Rate_LIN*method	ns	ns	ns	ns
Rate_LIN*season	ns	ns	ns	ns
Rate_QUA*method	ns	ns	ns	ns
Rate_QUA*season	ns	ns	ns	ns
Rate_LIN*M*S	Significant	ns	ns	ns

[1] Other factor combinations examined for significance, but not listed include Rate_CUB, Rate_FOR, Rate_CUB*method, Rate_CUB*season, Rate_FOR*method, Rate_FOR*season, season*method, Rate_QUA*M*S, Rate_CUB*M*S, and Rate_FOR*M*S

Table 4.3: Summary of significant canopy cover responses within the Mixed Prairie community in 2000.

Factor[1]	2000			
	Bunchgrass	Creeping Grasses	Sedge	Other
Method	ns	ns	ns	ns
Season	ns	ns	ns	ns
Rate_LIN	ns	ns	ns	Significant
Rate_QUA	ns	ns	ns	ns
Rate_LIN*method	ns	ns	ns	ns
Rate_LIN*season	ns	ns	ns	ns
Rate_QUA*method	ns	ns	ns	ns
Rate_QUA*season	Significant	ns	ns	ns
Rate_LIN*M*S	Significant	ns	ns	ns

[1] Other factor combinations examined for significance, but not listed include Rate_CUB, Rate_FOR, Rate_CUB*method, Rate_CUB*season, Rate_FOR*method, Rate_FOR*season, season*method, Rate_QUA*M*S, Rate_CUB*M*S, and Rate_FOR*M*S

Figure 4.1: Effect of rate of LHM application on crested wheatgrass canopy cover within the MB and CWG pastures in 1999.

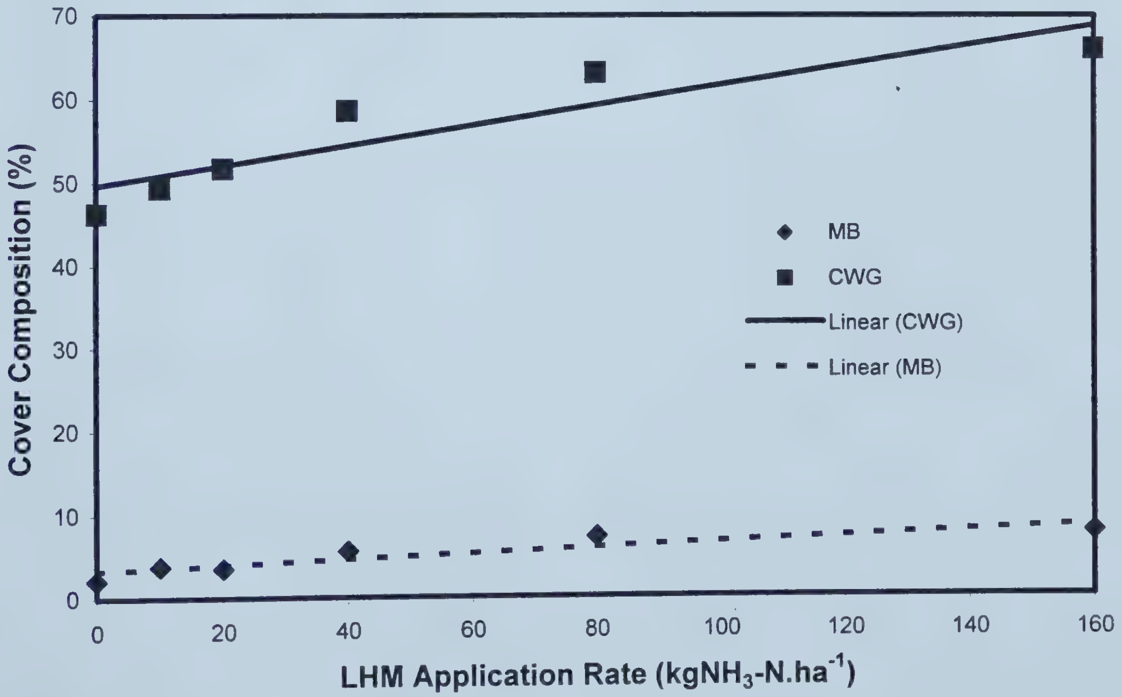


Figure 4.2: Effect of LHM application rate on total forb canopy cover within the MP community in 2000.

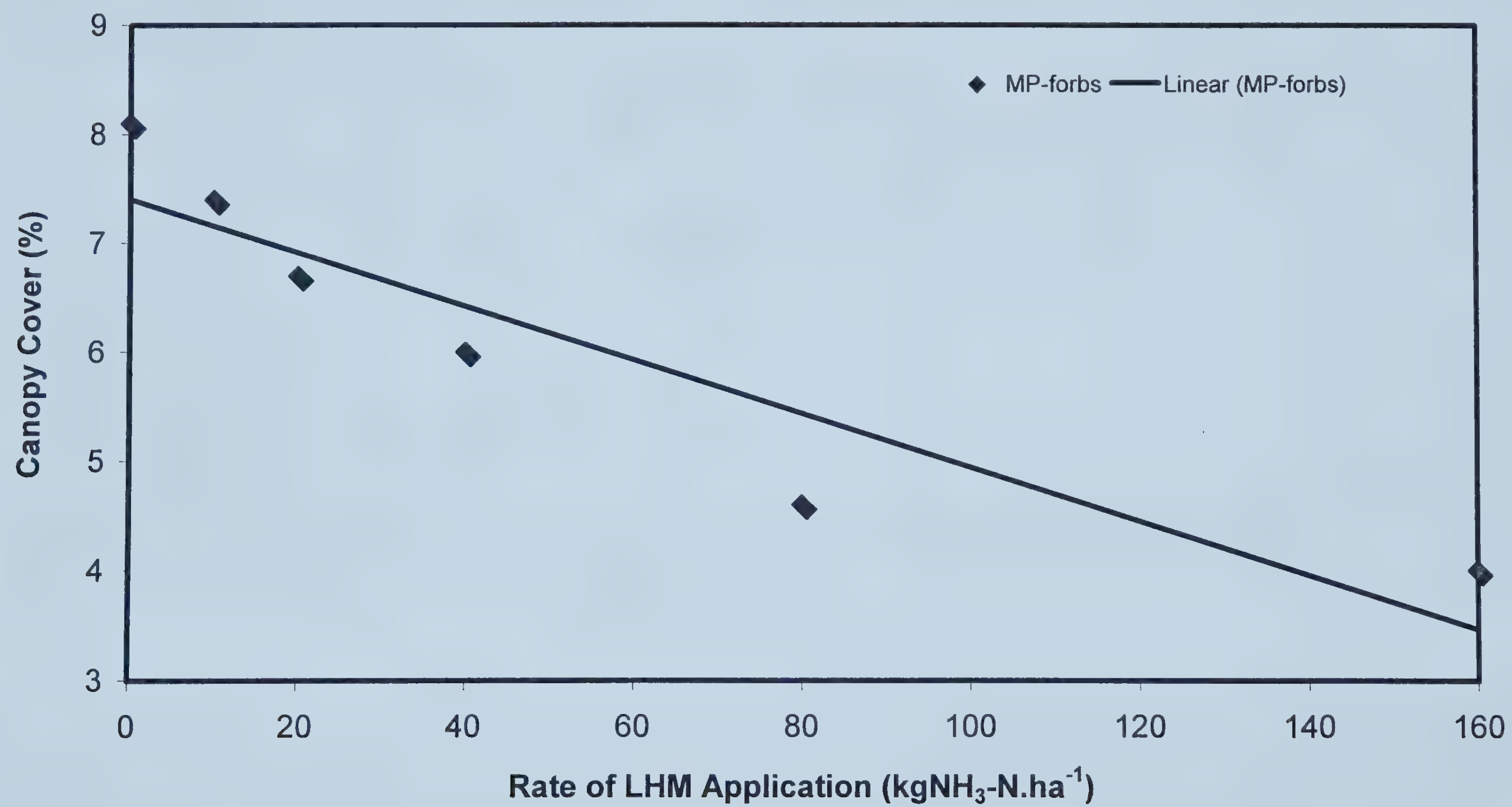


Table 4.4: Summary of significant seedhead production responses of dominant grass species within the Mixed Prairie community to in 1999 & 2000.

Factor[1]	1999			2000		
	Stipa spp.	Agropyron spp.	Koeleria macrantha	Stipa spp.	Agropyron spp.	Koeleria macrantha
Method	ns	ns	ns	ns	ns	ns
Season	ns	ns	ns	ns	ns	ns
Rate_LIN	ns	Significant	ns	ns	ns	ns
Rate_QUA	ns	ns	ns	ns	ns	ns
Rate_LIN*Method	ns	ns	ns	ns	ns	ns
Rate_LIN*Season	ns	ns	ns	ns	ns	ns
Rate_QUA*Method	ns	ns	ns	ns	ns	ns
Rate_QUA*Season	ns	ns	ns	ns	ns	Significant[2]
Method*Season	ns	ns	ns	ns	ns	ns
Rate_LIN*M*S	ns	ns	ns	ns	ns	ns

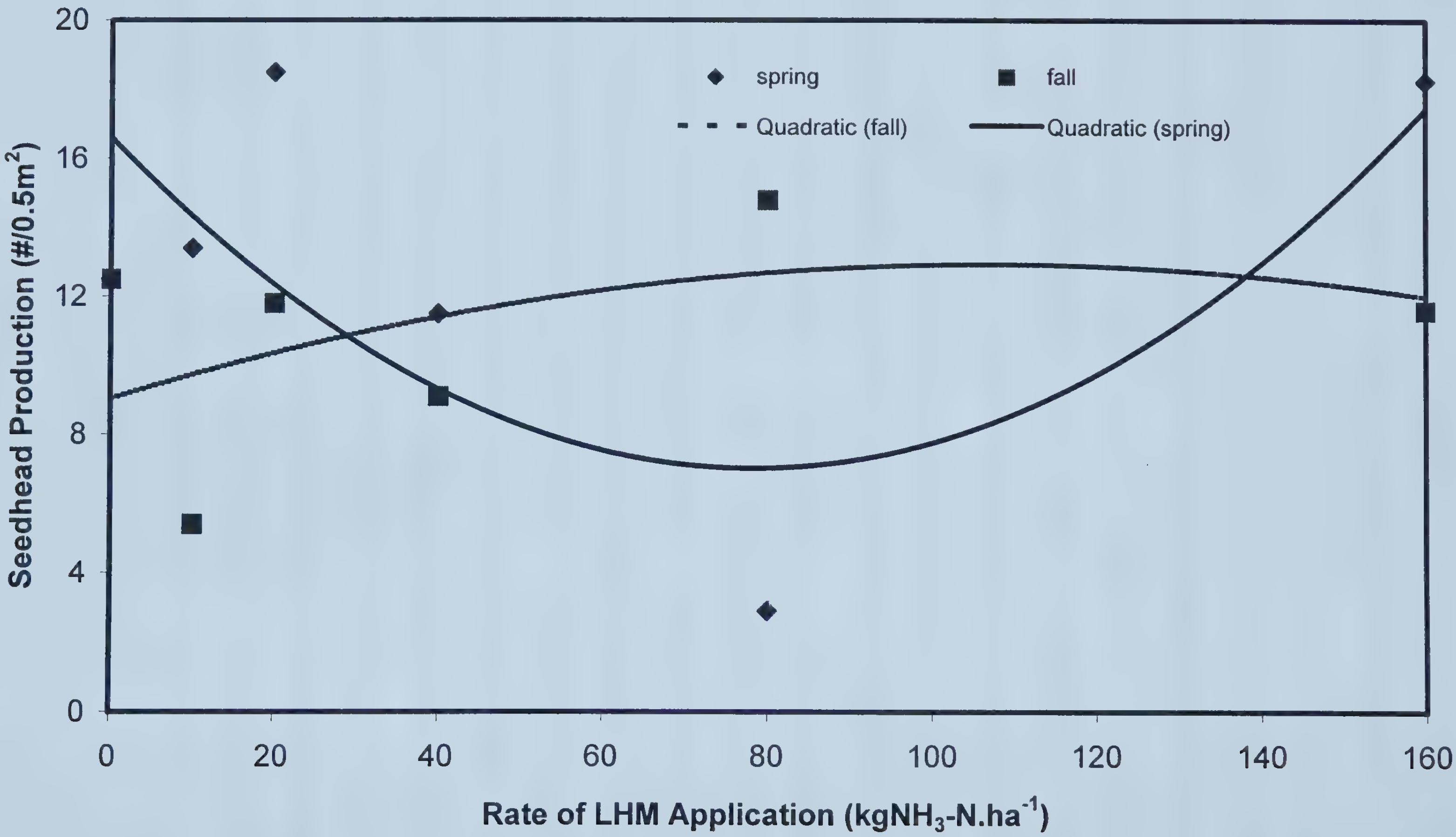
[1] Indicates other possible factor combinations examined for significance included Rate_CUB, Rate_FOR, Rate_CUB*method, Rate_CUB*season,Rate_FOR*method, Rate_FOR*season, season*method, Rate_QUA*M*S, Rate_CUB*M*S, and Rate_FOR*M*S
2 Indicates that Rate_FOR*method is also statistically significant

Table 4.5: Summary of significant seedhead production responses of plains rough fescue within the Fescue Grassland community to LHM in 1999 & 2000.

Factor[1]	*Festuca hallii*	
	1999	**2000**
Method	ns	**ns**
Season	ns	**ns**
Rate_LIN	ns	**Significant**
Rate_QUA	ns	ns
Rate_LIN*Method	ns	ns
Rate_LIN*Season	ns	ns
Rate_QUA*Method	ns	ns
Rate_QUA_Season	ns	ns
Method*Season	ns	ns
Rate_LIN*M*S	ns	ns

[1] Indicates other possible factor combinations examined for significance included Rate_CUB, Rate_FOR, Rate_CUB*method, Rate_CUB*season, Rate_FOR*method, Rate_FOR*season, season*method, Rate_QUA*M*S, Rate_CUB*M*S, and Rate_FOR*M*S

Figure 4.3: Effect of rate and season of LHM application on junegrass seedhead production within the MP community in 2000.



Chapter 5

Research Synthesis and Recommendations

Since the dawn of civilization, humans have attempted to manipulate their surroundings to maximize personal gains. Rangeland management is no different. There are numerous recorded incidents of humans manipulating rangelands for their own advantage: increased productivity and yield due to fertilization are not new concepts (Black and Wight 1979; Johnston et al. 1969; Johnston et al. 1967; Smoliak 1965). Widespread application of animal manure, however, is less established within North America, particularly on permanent forage lands. As such, there is little reliable information on animal manure application onto these areas, particularly native rangeland plant communities, including guidelines for appropriate application methodologies.

Intensive livestock operations (ILOs) are increasing in size and expanding in their geographic distribution within the province. This predicates the need for identifying new and appropriate sinks for manure disposal as production operations expand and manure quantities increase. In Alberta, a large number of hog operations have expanded into the south-central region, an area that is semi-arid and typically dominated by both native grasslands and seeded (e.g., agronomic) pastures. With this geographic shift, there has been increased interest in examining manure disposal options on adjacent land-bases, many of them permanent cover. However, it is imperitive that before liquid hog manure (LHM) application occurs on these lands on a widespread basis that an understanding is obtained as to what rates, methods and seasons of application deliver the most amenable agronomic responses without threatening the environmental sustainability of these areas.

Null hypotheses of this research initiative focused on plant community composition, forage quality and yield responses to three variables or combinations thereof. These variables were rate (10, 20, 40, 80 and 160 kgNH3-N.ha^{-1}), method (sub-surface injection vs. dribble broadcast) and season (fall vs. spring) of application. Objectives of this research included quantifying plant community

response variables to various combinations of the independent variables. Furthermore, this research sought to discern whether tame (e.g., introduced) forages and native grassland communities differed in their inherent response to LHM addition.

The hypothesis that increasing rates of LHM application would not increase forage yields and alter forage quality was rejected (Chapter 3). Graminoid forage yields were significantly increased in 1999 on all but the MB site. However, residual increases in forage yield were largely unapparent. Forage yield increases, where they occurred, were linear in nature, showing that the greatest agronomic (e.g., forage quality and quantity) benefits were seen at high levels of LHM application. Furthermore, relative increases in forage production were similar across study sites, dispelling the notion that native rangelands may be unsuited and relatively unresponsive to nutrient additions compared to tame forages. Accelerating rates of LHM application significantly reduced alfalfa yield on the MB site. This finding is in agreement with other relevant literature and is likely a result of competition among the graminoid and legume components for space, nutrient availability and moisture.

Accelerating rates of LHM application likewise increased graminoid forage quality. Again, this response was limited to immediate (e.g., 1999) forage quality changes and was further constrained mainly to crude protein (CP). Other dependant variables, including acid detergent fiber (ADF) and phosphorus (P) content were largely unaffected by increasing rates of LHM application.

Notably, crude protein yield (CPY) was also significantly increased within the graminoid component under accelerating rates of LHM application (Chapter 3). This variable is the product of forage quality and forage quantity. As such, CPY responses may be a better overall indicator of forage response than either yield or quality alone. On all sites, graminoid CPY increased in a linear manner with increasing rates of LHM application. Furthermore, this positive response was carried over into 2000 on all sites but the FG area. This finding alone suggests that there are positive, quantifiable benefits to applying LHM, both immediately and over the longer term, even when

climatic conditions are less favorable for plant growth (e.g., 1999 and 2000 were very wet and dry, respectively).

Although there were eminent concerns that higher levels of LHM application would generate undesirable changes in terms of plant community diversity and composition, such fears were largely unrealized (Chapter 4). Undesirable changes in the plant communities examined were either short-lived or not significant. This response suggests that both native and tame plant communities are capable of (vegetatively) buffering high nutrient additions, and are therefore relatively resistant to deleterious changes within the plant community following LHM application. That is not to say that plant communities were not altered in species composition following nutrient addition, but rather that the ecological changes observed were relatively minor. Nevertheless, care should still be taken to monitor for more extensive changes in the plant community, especially on native grasslands that are potentially more susceptible to ecological changes. Additional changes may serve as 'red flags' and signal more extensive changes in the future, particularly should repeated application occur on the same area. Seed head production was largely unaffected by the rate of LHM application, with the exception of the FG site (Chapter 4). On this plant community, residual (e.g., 2000) seed head production increased linearly with rate, exemplifying the differential response of native rangelands.

Overall, neither method nor season of LHM application generated consistent significant responses for any of the dependant variables examined (forage yield or quality, and species composition). Thus, the null hypotheses that method and season of application do not affect forage quantity, quality, community composition, and diversity appear to apply, at least under the conditions of this investigation. However, this result should be interpreted with some caution. Method and/or season of application may have generated subtle, but non-detectable, changes in all or some of the dependant variables examined here. When extrapolated over a large land-base these may be quite substantial. Similarly, these factors may affect future range and pasture vegetation characteristics on these sites. Furthermore, there may be associated benefits to incorporating LHM into the soil matrix relative to surface (e.g., broadcast) treatments. Injection technology reduces ammonia volatilization

(Brian Lambert, unpublished data), allowing for reduced atmospheric losses and presumably more effective capture of nutrients by plants.

Although the results of this research are encouraging, it is unlikely that these findings should be applied as a broad-scale prescription for future use, at least at high rates of LHM application. However, these results also support the notion the low to moderate rates of one-time LHM application (e.g., up to 40 $kg.ha^{-1}$) are unlikely to cause long-term, irreversible ecological degradation. As well, there are likely to be some geographic areas where LHM application is not appropriate at any rate (e.g., areas of high ecological and environmental significance), and its use in these areas should be discouraged.

Ultimately, given that every plant community is a unique entity with its own use history and plant community dynamics, LHM applications will have to be adjusted for site-specific factors. Even in the absence of nutrient addition, plant communities are edaphically and climatically pre-determined, resulting in considerable variation in forage response (Humpherys 1997). Climate plays an integral part in determining both forage and plant community response to LHM application. Land managers need to be cognizant of this fact and have the ability to remain flexible with their management goals and strategies.

Not only is every range association different in its response to fertilization, but there is also complex variation between individual plant species. "Each species in a community may be constrained by a different combination of resources whose pattern of availability may create a complex mosaic. This predicates an opportunistic decision-making framework for grassland management, as modified by the knowledge gained from previous local decisions" (Humphreys 1997).

In conclusion, though the results of this research suggest that LHM application onto forage lands within south-central Alberta is a feasible option with the potential for increased forage quality and quantity, there continues to be a need for additional research to further substantiate and refine these findings. Notably, future research should examine the response of different plant communities

to LHM application coupled with different grazing schedules. This information is needed in order to gain a broader understanding of how various tame pastures and native rangelands respond to LHM under different application methodologies. Further research in this regard and on a wide variety of soil types (e.g., soil textures) and under different climatic conditions would also help to better address the overall issue of land use compatibility between the hog and cattle industries of Alberta.

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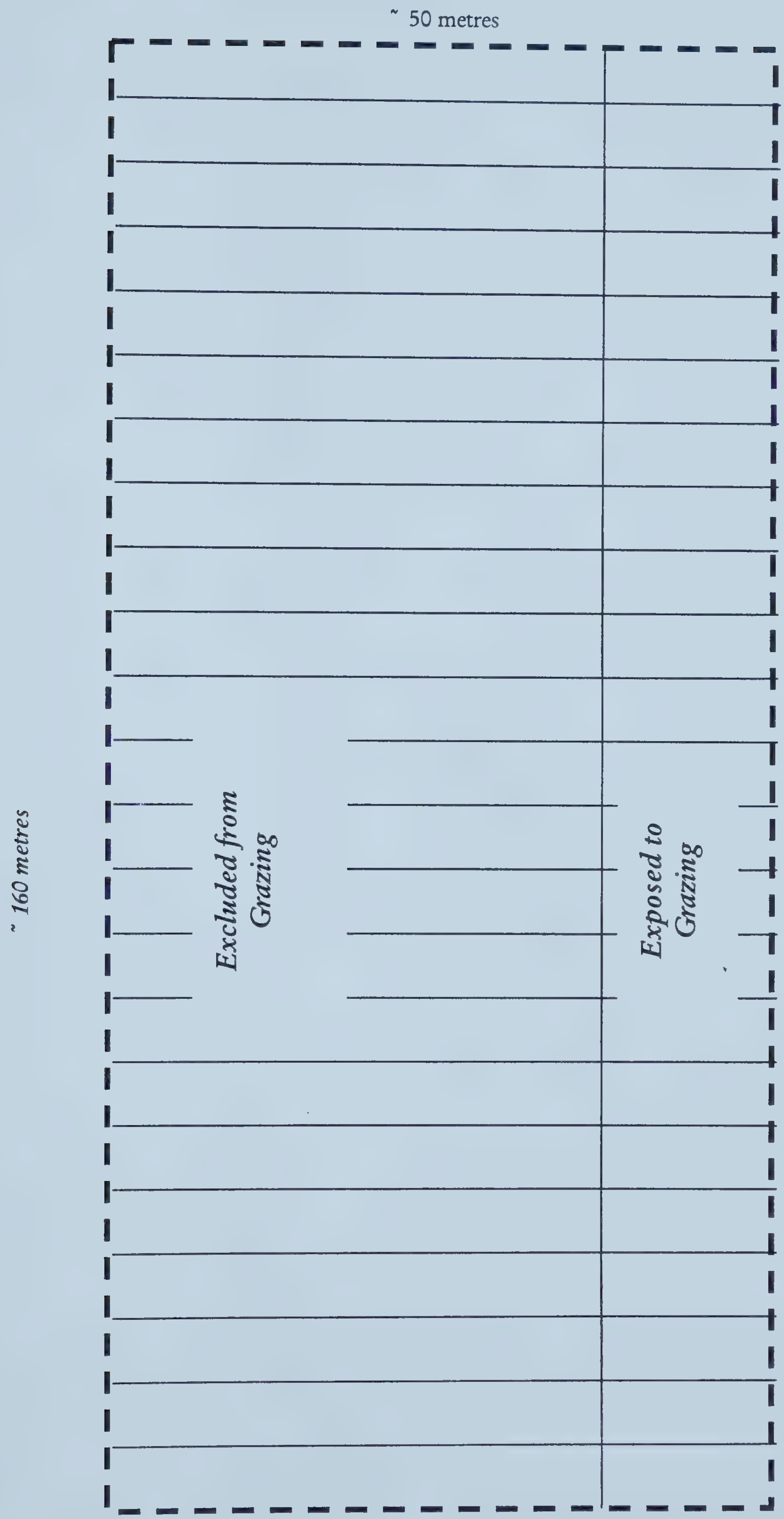
Appendix A

Study Area and Treatment Layout

Appendix A-I: Study Area With Respect to Alberta's Natural Regions

Appendix A-II: Site Layout



Appendix B

Reconnaissance Data

Appendix B-I: Reconnaissance Manure and Soil Nutrient Data

Table BI-1: Pre-treatment, mean (SD) soil characteristics in the 0-20cm zone for each of the native and tame sites investigated.

Constituent	Mixed Prairie	Fescue Grassland	Crested Wheatgrass - Alfalfa	Meadow Brome-Alfalfa
NH_4-N*	1.22 (0.72)	1.26 (0.54)	1.52 (0.77)	1.14 (0.37)
NO_3-N*	0.72 (0.66)	0.22 (0.22)	2.96 (2.15)	2.94 (1.11)
PO_4-P*	2.4 (0.55)	3.6 (0.89)	9 (2.55)	9 (2.83)
K*	471.2 (60.69)	334 (64.06)	337 (95.6)	213 (93.3)
SO_4-S*	9.98 (9.78)	4.24 (1.61)	5.04 (2.57)	2.48 (0.80)
Exch. Ca**	8 (3.51)	8.46 (2.19)	10.8 (5.52)	8.46 (2.63)
Exch. Mg**	3.44 (0.79)	3.24 (1.39)	4.02 (1.40)	1.44 (0.54)
Exch. Na**	0.44 (0.67)	0.12 (0.07)	0.84 (0.67)	<0.1 (0)
Exch. K**	0.89 (0.13)	0.69 (0.14)	0.64 (0.20)	0.47 (0.22)
E.C. (dS/m)	0.34 (0.16)	0.12 (0.03)	0.56 (0.41)	0.13 (0.022)
pH	6.6 (0.2)	6.28 (0.21)	6.96 (0.74)	6.58 (0.22)
O.M. %	3.86 (0.67)	4.94 (1.22)	3.22 (0.82)	3.22 (0.97)
Db ($Mg.m^{-3}$)	1.28 (?)	1.09 (?)	1.28 (?)	1.28 (?)
Total Sand	50.81 (?)	44.95 (?)	49.16 (?)	62.41 (?)
Total Silt	29.91 (?)	38.32 (?)	29.39 (?)	20.42 (?)
Total Clay	19.28 (?)	16.73 (?)	21.45 (?)	17.17 (?)

*=mg/kg
**=meq/100g

Table BI-2: Results of the manure analysis during application by truckload (n=7), April 1999.

Constituent	Mean $(SD)_{1-6}$	$Min._{1-6}$	$Max._{1-6}$	Sample 7*
Moisture %	99.34 (0.06)	99.3	99.46	99.76
NH_3-N %	0.21 (0.00)	0.21	0.21	0.10
NO_3-N %	0.01 (0.00)	0.01	0.01	<0.01
Kjeldahl N %	0.23 (0.01)	0.22	0.23	0.10
Organic N %	0.01 (0.01)	0.01	0.02	0.00
Total K_2O%	0.12 (0.00)	0.12	0.13	0.06
Total P_2O_5 %	0.06 (0.01)	0.05	0.07	0.02
Total S %	<0.01 (0.00)	<0.01	<0.01	<0.01
Ca%	0.01 (0)	0.01	0.01	0.01
Mg %	<0.01 (0.00)	<0.01	<0.01	<0.01
Na%	0.04 (0.00)	0.04	0.04	0.02
pH	7.67 (0.05)	7.6	7.7	7.80
E.C. ms/cm	17.62 (0.10)	17.5	17.7	8.87

*Sample 7 was diluted with water to reduce the manure concentration for treatments receiving LHM at 10 $kg.ha^{-1}$, as this low rate could not be achieved through normal operating conditions .

Appendix B-II: Cover Composition Reconnaissance Data for Dominant Plant Species on all Sites

Table BII-1: Summary of cover composition data (%) used to determine minimum sample sizes for each of the study sites

	Mixed Prairie Plant Community				
Plant Species	5 quadrats	10 quadrats	15 quadrats	20 quadrats	25 quadrats
Stipa spp.	4	5	4	4	5
Koeleria macrantha	10	9	8	8	8
Agropyron spp.	0.5	1	1	1.5	1
	Fescue Grassland Plant Community				
Festuca hallii	56	58	58	56	56
	Crested Wheatgrass-Alfalfa Pasture				
Medicago sativa	47	45	46	47	48
Agropyron cristatum	8	5	6	5	4
	Meadow Brome Alfalfa Pasture				
Medicago sativa	49	48	48	46	49
Bromus berbersteinii	28	24	26	26	25

Appendix C

Example of Use of Half-Normal Analysis Technique

```
data new;
input obs site $ method time rate rep grass forbs shrubs;
cards;

1    Fescue  1    1    1    1    1446   3    102
2    Fescue       1    1    2    1574   44   32
3    Fescue  1    1    1    3    2344   4    0
.
.
.
80   Fescue  2    2    5    4    6116   2    18
;

proc print;run;

proc sort;by site time method rate;run;

proc means noprint;by site time method rate;output out=new1 mean=;var grass;run;
proc glm;
  class time method rate;
  model grass=time method rate rate*time rate*method time*method rate*time*method;
Estimate 'LIN' rate -.426 -.344 -.180 0.148 0.802/divisor= .5;
Estimate 'QUA' rate 0.462 0.169 -.293 -.724 0.386/ divisor = .5;
Estimate 'CUB' rate -.481 0.208 0.689 -.495 0.079/ divisor = .5;
Estimate 'FOR' rate 0.416 -.781 0.455 -.098 0.008/ divisor = .5;
Estimate 'LIN_TIM' rate*time -.426 -.344 -.180 0.148 0.802
          0.426 0.344 0.180 -.148 -.802;
Estimate 'QUA_TIM' rate*time 0.462 0.169 -.293 -.724 0.386
          -.462 -.169 0.293 0.724 -.386;
Estimate 'CUB_TIM' rate*time -.481 0.208 0.689 -.495 0.079
          0.481 -.208 -.689 0.495 -.079;
Estimate 'FOR_TIM' rate*time 0.416 -.781 0.455 -.098 0.008
          -.416 0.781 -.455 0.098 -.008;
Estimate 'LIN_met' rate*method -.426 -.344 -.180 0.148 0.802
          0.426 0.344 0.180 -.148 -.802;
Estimate 'QUA_met' rate*method 0.462 0.169 -.293 -.724 0.386
          -.462 -.169 0.293 0.724 -.386;
Estimate 'CUB_met' rate*method -.481 0.208 0.689 -.495 0.079
          0.481 -.208 -.689 0.495 -.079;
Estimate 'FOR_met' rate*method 0.416 -.781 0.455 -.098 0.008
          -.416 0.781 -.455 0.098 -.008;
Estimate 'LIN3' rate*time*method -.426 -.344 -.180 0.148 0.802
         0.426 0.344  0.180 -.148 -.802
         0.426 0.344  0.180 -.148 -.802
         -.426 -.344 -.180 0.148 0.802 /divisor = 2;
Estimate 'CUB3' rate*time*method -.481 0.208 0.689 -.495 0.079
         0.481 -.208 -.689 0.495 -.079
         0.481 -.208 -.689 0.495 -.079
         -.481 0.208 0.689 -.495 0.079 /divisor = 2;
Estimate 'QUA3' rate*time*method 0.462 0.169 -.293 -.724 0.386
         -.462 -.169 0.293 0.724 -.386
         -.462 -.169 0.293 0.724 -.386
         0.462 0.169 -.293 -.724 0.386 /divisor = 2;
Estimate 'FOR3' rate*time*method  0.416 -.781 0.455 -.098 0.008
         -.416 0.781 -.455 0.098 -.008
         -.416 0.781 -.455 0.098 -.008
```

```
        0.416 -.781 0.455 -.098 0.008 /divisor = 2;
estimate 'time*meth' time*method 1 -1 -1 1/divisor=0.894427191;
estimate 'time' time 1 -1/divisor=0.632455532;
estimate 'meth' method 1 -1/divisor=0.632455532;
run;
```

Class Level Information

Class	Levels	Values
TIME	2	1 2
METHOD	2	1 2
RATE	5	1 2 3 4 5

Number of observations in data set = 20

General Linear Models Procedure

Dependent Variable: GRASS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	14244489.05000000	749709.95000000	.	.
Error	0	.	.		
Corrected Total	19	14244489.05000000			

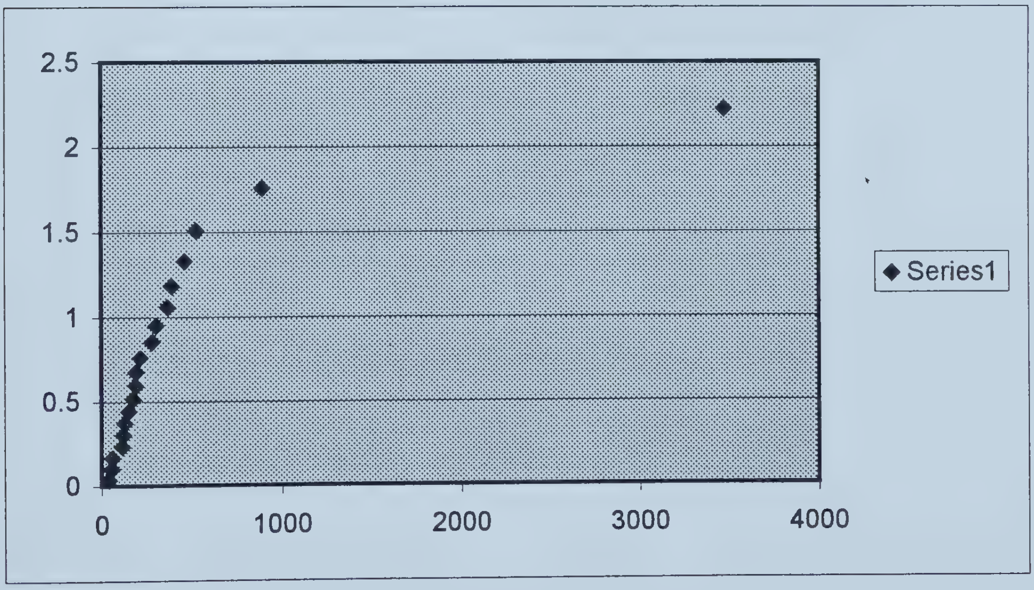
R-Square	C.V.	Root MSE	GRASS Mean
1.000000	0	0	2734.85000000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
TIME	1	2904.05000000	2904.05000000	.	.
METHOD	1	425152.80000000	425152.80000000	.	.
RATE	4	12145214.30000000	3036303.57500001	.	.
TIME*RATE	4	245158.70000000	61289.67500000	.	.
METHOD*RAT	4	1143538.70000001	285884.67500000	.	.
TIME*METHOD	1	132845.00000000	132845.00000000	.	.
TIME*METHOD*RATE	4	149675.50000000	37418.87500000	.	.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TIME	1	2904.05000000	2904.05000000	.	.
METHOD	1	425152.80000000	425152.80000000	.	.
RATE	4	12145214.30000000	3036303.57500000	.	.
TIME*RATE	4	245158.70000000	61289.67500000	.	.
METHOD*RATE	4	1143538.70000001	285884.67500000	.	.
TIME*METHOD	1	132845.00000000	132845.00000000	.	.
TIME*METHOD*RATE	4	149675.50000000	37418.87500000	.	.

Parameter	Estimate	T for H0:Parameter=0	Pr>|T|	Standard Error of Estimate
LIN	3470.45500	99999.99	0.0	0
QUA	-128.15900	99999.99	0.0	0
CUB	150.30800	99999.99	0.0	0
FOR	175.30500	99999.99	0.0	0
LIN_TIM	58.53200	99999.99	0.0	0
QUA_TIM	-298.99100	99999.99	0.0	0
CUB_TIM	386.91200	99999.99	0.0	0
FOR_TIM	52.69300	99999.99	0.0	0
LIN_met	-890.08200	99999.99	0.0	0
QUA_met	-526.67350	99999.99	0.0	0
CUB_met	-187.67550	99999.99	0.0	0
FOR_met	190.14450	99999.99	0.0	0
LIN3	278.53700	99999.99	0.0	0
CUB3	113.67750	99999.99	0.0	0
QUA3	-212.14750	99999.99	0.0	0
FOR3	118.32050	99999.99	0.0	0
time*meth	364.47908	99999.99	0.0	0
time	38.10545	99999.99	0.0	0
meth	-461.06008	99999.99	0.0	0

time	38.1	1	0.026316	0.513158	0.032987
FOR_tim	52.7	2	0.078947	0.539474	0.099108
LIN_tim	58.5	3	0.131579	0.565789	0.165664
CUB3	113.7	4	0.184211	0.592105	0.232964
FOR3	118.3	5	0.236842	0.618421	0.301336
QUA	128.2	6	0.289474	0.644737	0.371149
CUB	150.3	7	0.342105	0.671053	0.442822
FOR	175.3	8	0.394737	0.697368	0.516847
CUB_ME	187.7	9	0.447368	0.723684	0.59382
FOR_ME	190.1	10	0.5	0.75	0.67449
QUA3	212.1	11	0.552632	0.776316	0.75981
LIN3	278.5	12	0.605263	0.802632	0.851057
QUA_TIM	299.0	13	0.657895	0.828947	0.950013
time*meth	364.5	14	0.710526	0.855263	1.059277
CUB_TIM	386.9	15	0.763158	0.881579	1.182916
meth	461.1	16	0.815789	0.907895	1.327903
QUA_ME	526.7	17	0.868421	0.934211	1.507906
LIN_MET	890.1	18	0.921053	0.960526	1.756825
LIN	3470.5	19	0.973684	0.986842	2.221514



Appendix D

Forage Quality, Quantity and Utilization Data

Table DI-1: Mean 1999 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Crested Wheatgrass- Alfalfa pasture

Factor	Level	1999					
		Grass		Alfalfa		Weeds	
		x	sd	x	sd	x	sd
Season							
	fall	2698	1271	290	298	9	9
	spring	2870	1496	233	248	15	14
Method							
	broadcast	2930	1505	307	304	10	12
	injected	2730	1204	216	235	14	12
Rate							
	10	1580	576	261	313	11	8
	20	1634	558	284	204	19	15
	40	3082	860	276	188	9	9
	80	3415	633	238	316	12	15
	160	4439	1207	249	346	10	9
Controls							
	no till	1272		199		6	
	fall injected	1726		179		4	
	spring injected	1912		675		9	

Table DI-2: Mean 2000 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Crested Wheatgrass- Alfalfa pasture

Factor	Level	2000					
		Grass		Alfalfa		Weeds	
		x	sd	x	sd	x	sd
Season							
	fall	1134	433	43	78	0.3	1.1
	spring	1028	368	69	153	0.3	0.8
Method							
	broadcast	1031	378	40	76	0.4	1.2
	injected	1130	425	71	156	0.2	0.5
Rate							
	10	884	241	122	225	0.6	1.6
	20	1014	321	64	105	0.5	1.2
	40	1091	463	44	54	0.1	0.5
	80	1258	520	33	70	0.0	0.0
	160	1157	348	17	36	0.1	0.5
Controls							
	no till	994		230		1	
	fall injected	1177		99		0	
	spring injected	1076		145		0	

Table DI-3: Mean 1999 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Meadow Brome - Alfalfa pasture

Factor	Level	1999					
		Grass		Alfalfa		Weeds	
		x	sd	x	sd	x	sd
Season							
	fall	3125	1427	3042	1316	39	45
	spring	2782	1340	4042	1529	25	23
Method							
	broadcast	3089	1495	3854	1636	25	26
	injected	2819	1272	3342	1352	38	43
Rate							
	10	2221	1018	4170	1569	23	32
	20	2543	1022	3755	1574	17	12
	40	3387	1322	3583	1604	27	19
	80	3197	1548	3505	1219	37	33
	160	3420	1626	2978	1430	54	58
Controls							
	no till	2332		4128		14	
	fall injected	2068		4153		34	
	spring injected	1391		3155		24	

Table DI-4: Mean 2000 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Meadow Brome - Alfalfa pasture

Factor	Level	2000					
		Grass		Alfalfa		Weeds	
		x	sd	x	sd	x	sd
Season							
	fall	1009	405	1546	1132	14	82
	spring	842	315	1088	862	0.1	5
Method							
	broadcast	928	348	1189	950	13	82
	injected	923	396	1445	1094	1	5
Rate							
	10	797	293	1542	1054	0	0
	20	835	298	1624	1179	0.4	2
	40	1005	368	916	502	0	0
	80	874	349	1102	901	2	7
	160	1117	464	1401	1265	33	130
Controls							
	no till	1588		3155		0	
	fall injected	611		1121		1	
	spring injected	878		1149		0	

Table DI-5: Mean 1999 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Fescue Grassland community

Factor	Level	1999			
		Grass		Forb	
		x	sd	x	sd
Season					
	fall	2589	709	109	106
	spring	2881	1087	141	164
Method					
	broadcast	2747	934	96	102
	injected	2723	923	154	163
Rate					
	10	1963	326	78	106
	20	2075	278	114	65
	40	2532	403	132	192
	80	2993	290	164	134
	160	4112	891	137	160
Controls					
	no till	2366		91	
	fall injected	1725		51	
	spring injected	1536		84	

Table DI-6: Mean 2000 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Fescue Grassland community

Factor	Level	2000			
		Grass		Forb	
		x	sd	x	sd
Season					
	fall	1407	351	41	53
	spring	1504	397	25	32
Method					
	broadcast	1416	383	22	27
	injected	1494	369	43	54
Rate					
	10	1519	393	36	35
	20	1468	466	29	26
	40	1366	348	29	31
	80	1496	345	20	36
	160	1429	342	51	74
Controls					
	no till	1224		26	
	fall injected	1435		77	
	spring injected	1668		27	

Table DI-7: Mean 1999 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Mixed Prairie community

Factor	Level	1999			
		Grass		Forb	
		x	sd	x	sd
Season					
	fall	1180	680	451	397
	spring	1332	788	457	296
Method					
	broadcast	1148	607	396	321
	injected	1411	815	512	368
Rate					
	10	740	227	247	130
	20	785	348	240	94
	40	1109	444	318	166
	80	1535	526	622	383
	160	2228	741	843	364
Controls					
	no till	486		184	
	fall injected	444		192	
	spring injected	500		159	

Table DI-8: Mean 2000 ANPP (kg.ha^{-1}, +/-standard deviation) for treatment factors on the Mixed Prairie community

Factor	Level	2000			
		Grass		Forb	
		x	sd	x	sd
Season					
	fall	680	484	43	36
	spring	634	296	51	44
Method					
	broadcast	572	326	43	41
	injected	742	450	50	39
Rate					
	10	579	224	66	45
	20	649	632	78	45
	40	638	370	42	38
	80	556	248	22	13
	160	862	359	25	15
Controls					
	no till	373		45	
	fall injected	409		125	
	spring injected	517		75	

Table DII-1: Mean 1999 Graminoid Forage Quality (%, +/-standard deviation) for treatment factors on the Crested Wheatgrass- Alfalfa pasture

Factor	Level	1999					
		Crude Protein		Phosphorus		Acid Detergent Fiber	
		x	sd	x	sd	x	sd
Season							
	fall	7.7	1.6	0.17	0.02	32.5	1.7
	spring	7.8	1.3	0.16	0.03	30.8	0.9
Method							
	broadcast	7.3	1.1	0.15	0.02	31.2	1.6
	injected	8.2	1.6	0.18	0.02	32.1	1.5
Rate							
	10	7.3	0.9	0.18	0.02	30.8	1.7
	20	7.2	0.9	0.16	0.03	31.1	0.5
	40	7.1	0.7	0.15	0.03	32.1	1.7
	80	7.4	1.0	0.15	0.02	31.7	1.5
	160	9.8	1.6	0.17	0.02	32.5	2.2

Table DII-2: Mean 1999 graminoid forage quality (%, +/-standard deviation) for treatment factors on the Meadow Brome – Alfalfa pasture

Factor	Level	1999					
		Crude Protein		Phosphorus		Acid Detergent Fiber	
		x	sd	x	sd	x	sd
Season							
	fall	6.0	1.2	0.15	0.03	40.4	2.0
	spring	6.8	1.8	0.15	0.02	40.7	1.5
Method							
	broadcast	5.9	1.4	0.15	0.03	40.8	2.0
	injected	6.9	1.6	0.15	0.02	40.3	1.5
Rate							
	10	4.8	0.3	0.13	0.03	42.7	1.3
	20	6.3	0.6	0.16	0.03	41.0	1.8
	40	5.8	1.0	0.13	0.01	40.5	0.6
	80	6.7	1.7	0.16	0.03	38.3	0.5
	160	8.4	1.1	0.17	0.02	40.3	0.7

Table DII-3: Mean 1999 graminoid forage quality(%, +/-standard deviation) for treatment factors on the Fescue Grassland community

Factor	Level	1999					
		Crude Protein		Phosphorus		Acid Detergent Fiber	
		x	sd	x	sd	x	sd
Season							
	fall	7.2	1.0	0.16	0.01	41.0	1.4
	spring	7.7	0.8	0.16	0.02	41.3	1.1
Method							
	broadcast	7.4	1.1	0.16	0.02	40.6	1.3
	injected	7.5	0.8	0.16	0.01	41.8	0.9
Rate							
	10	7.0	0.5	0.15	0.003	41.4	0.4
	20	6.9	0.4	0.15	0.01	41.9	0.5
	40	7.1	0.3	0.15	0.01	41.1	0.3
	80	7.1	0.4	0.15	0.01	40.0	1.7
	160	9.1	0.6	0.18	0.02	41.8	2.0

Table DII-4: Mean 1999 graminoid forage quality (%, +/-standard deviation) for treatment factors on the Mixed Prairie community

Factor	Level	1999					
		Crude Protein		Phosphorus		Acid Detergent Fiber	
		x	sd	x	sd	x	sd
Season							
	fall	8.2	0.8	0.15	0.01	41.0	1.4
	spring	8.2	0.9	0.15	0.01	39.2	1.3
Method							
	broadcast	8.1	0.9	0.15	0.02	40.2	1.6
	injected	8.2	0.7	0.15	0.01	40.1	1.7
Rate							
	10	8.5	0.3	0.15	0.02	39.3	1.3
	20	7.6	0.4	0.15	0.02	39.6	0.9
	40	7.4	0.4	0.15	0.01	40.9	2.6
	80	8.4	0.8	0.14	0.01	40.3	1.1
	160	9.0	0.8	0.16	0.01	40.5	1.8

Table DII-5: Mean 1999 alfalfa forage quality (%, +/-standard deviation) for treatment factors on the Meadow Brome – Alfalfa pasture

Factor	Level	1999					
		Crude Protein		Phosphorus		Acid Detergent Fiber	
		x	sd	x	sd	x	sd
Season							
	fall	14.9	0.8	0.18	0.02	34.7	2.3
	spring	14.5	1.0	0.18	0.02	35.2	2.5
Method							
	broadcast	14.4	1.0	0.17	0.02	35.4	2.8
	injected	14.9	0.7	0.19	0.02	34.5	1.9
Rate							
	10	14.1	1.2	0.16	0.01	35.0	1.7
	20	14.6	0.8	0.17	0.02	35.9	1.8
	40	14.7	1.0	0.19	0.03	34.4	2.0
	80	14.5	0.4	0.19	0.01	35.1	2.3
	160	15.4	0.9	0.20	0.02	34.5	4.2

Table DII-6: Mean 2000 graminoid forage quality (%, +/- standard deviation) for treatment factors on a Crested Wheatgrass – Alfalfa pasture

Factor	Level	2000			
		Crude Protein		Acid Detergent Fiber	
		x	sd	x	sd
Season					
	fall	5.5	1.3	37.3	4.6
	spring	5.2	1.6	39.3	1.3
Method					
	broadcast	5.5	1.4	38.2	4.3
	injected	5.2	1.5	38.2	2.6
Rate					
	10	5.4	0.8	37.3	1.8
	20	5.2	1.4	36.4	2.7
	40	4.9	0.7	38.0	2.5
	80	4.3	0.4	40.0	2.7
	160	6.9	2.1	39.9	5.7

Table DII-7: Mean 2000 graminoid forage quality (%, +/- standard deviation) for treatment factors on the Meadow Brome – Alfalfa pasture

Factor	Level	2000			
		Crude Protein		Acid Detergent Fiber	
		x	sd	x	sd
Season					
	fall	8.0	1.7	40.1	6.9
	spring	8.2	1.1	37.4	1.4
Method					
	broadcast	7.8	1.1	38.0	1.5
	injected	8.4	1.6	39.5	7.0
Rate					
	10	7.2	0.3	39.1	1.9
	20	8.0	0.6	38.2	2.3
	40	7.0	0.8	38.0	1.1
	80	8.8	1.0	37.2	1.7
	160	9.5	1.9	41.4	11.0

Table DII-8: Mean 2000 graminoid forage quality (%, +/- standard deviation) for treatment factors on the Fescue Grassland community

Factor	Level	2000			
		Crude Protein		Acid Detergent Fiber	
		x	sd	x	sd
Season					
	fall	6.1	0.4	43.9	1.3
	spring	5.7	0.8	44.4	1.8
Method					
	broadcast	6.0	0.7	44.5	1.1
	injected	5.9	0.6	43.6	1.9
Rate					
	10	6.0	0.6	44.2	1.5
	20	6.1	0.6	45.0	0.7
	40	5.4	0.7	44.7	1.5
	80	5.8	0.6	43.6	1.0
	160	6.3	0.3	42.7	2.0

Table DII-9: Mean 2000 graminoid forage quality (%, +/- standard deviation) for treatment factors on the Mixed Prairie community

Factor	Level	2000			
		Crude Protein		Acid Detergent Fiber	
		x	sd	x	sd
Season					
	fall	5.5	1.1	42.4	3.1
	spring	5.5	1.5	41.6	2.4
Method					
	broadcast	5.9	1.2	40.7	4.3
	injected	5.1	1.3	43.3	2.6
Rate					
	10	5.1	0.5	42.6	1.8
	20	4.5	1.1	43.4	2.7
	40	5.9	1.3	40.9	2.5
	80	5.2	0.4	42.3	3.1
	160	7.0	1.5	40.8	3.5

Table DII-10: Mean 2000 alfalfa forage quality (%, +/- standard deviation) for treatment factors on the Meadow Brome – Alfalfa pasture

Factor	Level	2000			
		Crude Protein		Acid Detergent Fiber	
		x	sd	x	sd
Season					
	fall	11.6	1.5	39.7	2.6
	spring	11.7	0.5	38.1	3.0
Method					
	broadcast	11.5	1.0	39.1	2.6
	injected	11.8	1.2	38.7	3.2
Rate					
	10	10.9	0.9	40.3	2.5
	20	11.6	1.1	39.3	2.4
	40	11.4	0.9	38.5	3.3
	80	11.5	0.7	38.7	2.5
	160	12.8	1.2	37.7	3.7

Table DIII-1: Mean graminoid CPY (kg.ha^{-1}, +/- standard deviation) for treatment factors on the Mixed Prairie community in 1999 & 2000

Factor	Level	1999		2000	
		x	sd	x	sd
Season					
	fall	97	58	36	20
	spring	111	72	35	18
Method					
	broadcast	90	55	33	18
	injected	118	73	38	21
Rate					
	10	63	19	29	10
	20	60	26	26	21
	40	82	34	36	18
	80	127	40	28	12
	160	201	79	57	18

Table DIII-2: Mean graminoid CPY (kg.ha^{-1}, +/- standard deviation) for treatment factors on the Fescue Grassland community in 1999 & 2000

Factor	Level	1999		2000	
		x	sd	x	sd
Season					
	fall	191	75	86	22
	spring	228	113	86	26
Method					
	broadcast	213	102	84	25
	injected	206	94	88	23
Rate					
	10	138	25	90	25
	20	153	23	90	32
	40	181	35	73	19
	80	211	20	87	19
	160	373	87	90	21

Table DIII-3: Mean graminoid CPY (kg.ha^{-1}, +/- standard deviation) for treatment factors on the Crested Wheatgrass-Alfalfa pasture in 1999 & 2000

Factor	Level	1999		2000	
		x	sd	x	sd
Season					
	fall	211	113	61	24
	spring	230	146	53	23
Method					
	broadcast	222	123	56	22
	injected	220	139	59	26
Rate					
	10	113	38	47	12
	20	116	39	52	18
	40	218	62	53	22
	80	250	88	55	25
	160	422	83	79	28

Table DIII-4: Mean graminoid CPY (kg.ha^{-1}, +/- standard deviation) for treatment factors on the Meadow Brome-Alfalfa pasture in 1999 & 2000

Factor	Level	1999		2000	
		x	sd	x	sd
Season					
	fall	190	101	82	41
	spring	192	116	70	29
Method					
	broadcast	186	107	72	30
	injected	197	109	79	41
Rate					
	10	106	48	57	20
	20	158	58	67	26
	40	192	65	70	27
	80	212	108	77	32
	160	289	142	108	48

Table DIII-5: Mean alfalfa CPY (kg.ha^{-1}, +/- standard deviation) for treatment factors on the Meadow Brome-Alfalfa pasture in 1999 & 2000

Factor	Level	1999		2000	
		x	sd	x	sd
Season					
	fall	450	196	184	149
	spring	581	217	126	97
Method					
	broadcast	537	234	137	111
	injected	495	197	173	143
Rate					
	10	582	210	165	109
	20	544	225	194	152
	40	484	232	104	55
	80	508	182	127	102
	160	461	234	187	179

Table DIV-1: Mean grass utilization (+/-standard deviation) and relative percents to treatment factors on the Crested Wheatgrass-Alfalfa pasture in 1999

Factor	Level	1999		
		% utilization	forage removed	sd
Season				
	fall	59%	1668.8	1028.3
	spring	53%	1550.7	1040.5
Method				
	broadcast	55%	1689.8	893.7
	injected	56%	1529.7	1155.7
Rate				
	10	40%	597.8	383.8
	20	61%	1072.8	478.8
	40	73%	2415.8	871.8
	80	47%	1663.3	1106.3
	160	52%	2299.3	910.5

Appendix E

Community Diversity, Richness, Composition and Seed Head Production Data

Table EI-1: Mean canopy cover composition of dominant plants (%, +/-standard deviation) relative to treatment factors on the Meadow Brome-Alfalfa pasture in 1999 and 2000

Factor	Level	1999							
		Alfalfa		Meadow Brome		Crested Wheatgrass		Other	
		x	sd	x	sd	x	sd	x	sd
Season									
	fall	57.7	21.1	17.8	12.6	6.1	7.3	7.0	6.7
	spring	60.2	19.8	18.7	12.8	5.3	8.0	6.9	6.8
Method									
	broadcast	60.8	21.4	16.5	9.8	6.2	8.1	6.4	6.7
	injected	57.1	19.4	20.0	14.9	5.2	7.1	7.5	6.8
Rate									
	10	66.6	15.8	16.4	13.4	3.9	5.6	6.3	4.8
	20	62.8	18.3	17.0	10.1	3.9	5.9	5.5	6.1
	40	55.9	21.3	17.6	11.7	5.6	7.4	5.3	4.7
	80	53.6	19.7	20.6	13.4	7.2	8.6	8.6	8.1
	160	55.8	24.1	19.5	14.5	7.7	9.5	9.0	8.5
Controls									
	true control	65.0		14.7		1.4		6.3	
	fall injected	65.0		13.1		1.9		9.9	
	spring injected	61.0		18.1		4.0		11.1	
		2000							
		x	sd	x	sd	x	sd	x	sd
Season									
	fall	28.1	18.3	18.3	12.0	5.6	5.9	4.1	8.6
	spring	23.8	13.6	19.3	12.9	4.2	5.1	1.7	2.9
Method									
	broadcast	26.0	16.2	19.9	12.0	5.2	5.6	1.7	4.3
	injected	25.9	16.4	17.7	12.8	4.6	5.5	4.1	7.9
Rate									
	10	29.0	17.0	20.2	13.6	5.0	5.1	3.4	5.7
	20	28.0	15.0	16.1	13.5	5.1	5.7	3.8	7.2
	40	24.4	15.2	16.5	7.4	5.3	4.9	1.2	3.2
	80	22.0	15.2	20.7	13.4	3.6	5.1	2.7	4.5
	160	22.7	16.0	20.7	14.6	5.0	6.5	4.2	9.7
Controls									
	true control	34.7		15.3		3.3		5.4	
	fall injected	25.1		13.5		4.7		3.8	
	spring injected	20.3		23.9		3.1		1.1	

Table EI-2: Mean canopy cover composition of dominant plants (%, +/-standard deviation) relative to treatment factors on the Crested Wheatgrass-Alfalfa pasture in 1999 and 2000

Factor	Level	1999					
		Perennial Grass[1]		Alfalfa		Other	
		x	sd	x	sd	x	sd
Season							
	fall	59.2	10.0	15.4	13.9	2.4	3.9
	spring	63.0	12.7	14.2	12.8	1.8	2.7
Method							
	broadcast	63.2	11.2	15.6	13.7	1.9	3.2
	injected	59.0	11.6	14.0	12.9	2.4	3.5
Rate							
	10	52.5	7.7	13.7	12.0	2.3	3.6
	20	56.4	11.0	14.4	12.3	3.6	3.8
	40	62.5	11.7	20.7	15.2	1.5	3.4
	80	66.1	7.4	13.3	13.2	1.8	2.4
	160	68.1	11.7	11.9	12.6	1.5	3.2
Controls							
	true control	55.4		10.7		1.3	
	fall injected	51.7		11.7		1.6	
	spring injected	49.9		40.2		1.8	
		2000					
		x	sd	x	sd	x	sd
Season							
	fall	36.2	10.0	4.5	6.1	0.1	0.5
	spring	33.3	9.4	4.7	6.0	0.4	1.2
Method							
	broadcast	34.9	10.7	4.5	6.0	0.2	1.0
	injected	34.6	8.9	4.7	6.1	0.2	0.8
Rate							
	10	31.9	9.1	7.2	6.3	0.4	1.0
	20	28.2	7.8	7.7	7.8	0.5	1.5
	40	37.8	8.7	5.7	6.0	0.1	0.4
	80	37.2	10.5	1.2	2.1	0.1	0.6
	160	38.6	8.8	1.2	1.8	0.0	1.0
Controls							
	true control	32.8		9.0		0.4	
	fall injected	33.3		8.5		0	
	spring injected	32.2		10.1		0	

[1] Perennial grass component is comprised mainly of crested wheatgrass with minor amount of Russian wildrye.

Table EI-3: Mean canopy cover composition of functional plant groups (%, +/-standard deviation) relative to treatment factors on the Fescue Grassland community in 1999 and 2000.

Factor	Level	1999					
		Perennial Grass		Sedge		Other	
		x	sd	x	sd	x	sd
Season							
	fall	51.3	11.1	8.3	8.0	10.4	11.5
	spring	52.0	12.1	7.4	5.5	9.4	7.9
Method							
	broadcast	48.5	12.4	9.4	8.7	8.4	8.5
	injected	54.8	9.9	6.2	3.7	11.3	10.9
Rate							
	10	50.9	8.6	5.9	3.3	6.6	7.7
	20	49.3	10.4	6.3	4.4	10.0	8.3
	40	50.8	12.8	9.4	11.0	8.3	7.4
	80	55.1	10.7	7.4	3.9	12.1	9.1
	160	52.2	14.4	10.2	7.6	12.4	14.3
Controls							
	true control	40.1		4.6		14.2	
	fall injected	48.5		5.2		10.0	
	spring injected	55.1		4.7		10.3	
		2000					
		x	sd	x	sd	x	sd
Season							
	fall	38.5	9.9	5.8	7.3	6.8	4.7
	spring	39.9	10.0	5.5	6.3	6.6	4.0
Method							
	broadcast	36.9	10.7	4.1	4.4	7.2	5.0
	injected	41.5	8.6	7.3	8.3	6.2	3.5
Rate							
	10	38.9	9.1	5.6	6.7	7.1	4.7
	20	40.5	10.4	4.7	4.2	5.8	2.9
	40	37.9	10.5	4.6	5.2	8.0	5.2
	80	41.1	9.4	5.1	6.5	6.0	2.1
	160	37.5	10.4	8.4	9.6	6.7	5.5
Controls							
	true control	35.0		5.9		6.1	
	fall injected	44.9		6.0		3.9	
	spring injected	38.5		6.3		4.6	

Table EI-4: Mean canopy cover composition of functional plant groups (%, +/-standard deviation) relative to treatment factors on the Mixed Prairie community in 1999 and 2000.

Factor	Level	1999							
		Bunchgrass		Sedge		Other		Rhizomatous Grass	
		x	sd	x	sd	x	sd	x	sd
Season									
	fall	36.6	12.2	15.5	5.7	11.2	8.4	6.4	6.2
	spring	40.1	11.3	16.9	7.2	13.9	9.6	7.3	8.1
Method									
	broadcast	37.3	11.4	15.8	6.8	11.3	8.0	8.0	8.1
	injected	39.5	12.3	16.2	6.3	13.7	10.0	5.7	5.9
Rate									
	10	33.9	10.1	16.5	5.4	12.4	9.2	5.6	6.0
	20	36.0	10.4	17.6	7.1	14.4	11.2	6.7	6.5
	40	39.1	11.3	15.5	6.5	12.2	7.9	5.6	5.0
	80	44.0	11.9	15.5	6.4	11.7	8.6	6.7	7.4
	160	38.8	13.3	15.1	6.9	11.9	8.4	9.8	9.5
Controls									
	true control	28.0		17.2		25.1		7.6	
	fall injected	30.7		16.8		27.7		4.5	
	spring injected	28.9		15.4		18.9		4.9	
		2000							
		x	sd	x	sd	x	sd	x	sd
Season									
	fall	22.3	8.2	8.9	3.6	5.4	3.8	0.8	1.1
	spring	23.1	8.9	8.7	3.9	6.1	4.7	0.7	1.2
Method									
	broadcast	21.6	7.7	8.4	3.4	6.2	4.5	0.9	1.3
	injected	23.7	9.2	9.2	4.0	5.3	3.9	0.6	0.9
Rate									
	10	22.5	7.6	8.1	3.7	7.4	5.4	0.9	1.0
	20	20.9	9.0	8.9	3.1	6.7	4.7	0.9	1.2
	40	21.9	6.8	9.5	4.1	6.0	3.4	0.7	0.9
	80	23.5	10.5	9.1	4.0	4.6	3.5	0.4	0.9
	160	24.5	8.0	8.5	3.6	4.0	2.9	1.0	1.5
Controls									
	true control	16.9		8.4		7.8		2.3	
	fall injected	19.5		9.6		8.3		2.9	
	spring injected	22.7		5.9		8.4		2.1	

Table EII-1: Mean seed head counts (#/0.5m^2) of dominant species (+/- standard deviation) among treatment factors on the Meadow Brome-Alfalfa pasture in 1999 and 2000

Factor	Level	1999				2000	
		Crested Wheatgrass		Meadow Brome		Crested Wheatgrass	
		x	sd	x	sd	x	sd
Season							
	fall	28	25	66	35	12	11
	spring	22	20	59	29	12	13
Method							
	broadcast	26	23	66	33	12	13
	injected	24	22	58	32	12	12
Rate							
	10	18	12	70	40	10	9
	20	29	25	57	27	10	9
	40	27	28	70	24	17	16
	80	24	22	56	33	11	15
	160	28	24	59	36	12	9
Controls							
	true control	33		62		9	
	fall injected	17		37		15	
	spring injected	8		40		14	

Table EII-2: Mean seed head counts (#/0.5m^2) of dominant species (+/- standard deviation) among treatment factors on the Crested Wheatgrass – Alfalfa pasture in 1999 and 2000

Factor	Level	Crested Wheatgrass			
		1999		2000	
		x	sd	x	sd
Season					
	fall	326	243	12	13
	spring	114	159	8	24
Method					
	broadcast	196	224	11	23
	injected	243	237	10	15
Rate					
	10	91	76	14	20
	20	122	119	19	32
	40	260	242	5	4
	80	264	560	3	3
	160	362	283	11	18
Controls					
	True control	98		3	
	Fall injection	89		17	
	Spring injectio	97		16	

Table EII-3: Mean seed head counts (#/0.5m^2) of dominant species (+/- standard deviation) among treatment factors on the Crested Wheatgrass – Alfalfa pasture in 1999 and 2000

Factor	Level	Plains Rough Fescue			
		1999		2000	
		x	sd	x	sd
Season					
	fall	13	10	46	33
	spring	14	14	48	34
Method					
	broadcast	13	12	49	33
	injected	14	12	45	34
Rate					
	10	10	10	32	24
	20	12	9	40	29
	40	11	10	45	22
	80	16	12	50	18
	160	18	17	70	52
Controls					
	true control	38		50	
	fall injection	4		24	
	spring injection	5		34	

Table EII-4: Mean seed head counts (#/0.5m^2) of dominant species (+/- standard deviation) among treatment factors on the Mixed Prairie community in 1999

Factor	Level	1999					
		Junegrass		Speargrass		Wheatgrass	
		x	sd	x	sd	x	sd
Season							
	fall	33	36	28	19	2.0	3.8
	spring	10	10	33	20	0.8	1.8
Method							
	broadcast	26	34	33	21	1.3	2.5
	injected	17	21	28	19	1.5	3.4
Rate							
	10	28	26	26	14	0.1	0.3
	20	16	24	35	21	0.2	0.4
	40	28	47	22	17	0.4	1.1
	80	11	14	37	22	2.0	2.8
	160	25	20	32	21	4.5	5.0
Controls							
	true control	10		14		0	
	fall control	8		17		0	
	spring control	21		40		0	

Table EII-5: Mean seed head counts ($\#/0.5m^2$) of dominant species (+/-standard deviation) among treatment factors on the Mixed Prairie community in 2000

Factor	Level	2000					
		Junegrass		Speargrass		Wheatgrass	
		x	sd	x	sd	x	sd
Season							
	fall	11	8	16	16	0.5	2.3
	spring	13	14	21	18	0.2	0.7
Method							
	broadcast	26	10	55	20	1.4	2.3
	injected	32	12	37	13	0.3	0.6
Rate							
	10	9	12	22	13	0.3	1.0
	20	15	11	27	18	0.2	0.5
	40	10	9	19	20	0.2	0.8
	80	9	9	16	21	0	0
	160	15	14	8	7	1.0	3.5
Controls							
	true control	3		22		0	
	fall control	25		49		2	
	spring control	19		26		0	

Table EIII-1: Mean community diversity and richness indices (+/-standard deviation) among treatment factors on the Meadow Brome-Alfalfa pasture in 1999 and 2000

Factor	Level	Diversity			
		1999		2000	
		x	sd	x	sd
Season					
	fall	0.4938	0.09	0.4893	0.06
	spring	0.4586	0.08	0.4485	0.04
Method					
	broadcast	0.4623	0.09	0.4485	0.04
	injected	0.4901	0.08	0.4920	0.06
Rate					
	10	0.4198	0.04	0.4839	0.04
	20	0.4170	0.04	0.4456	0.07
	40	0.4620	0.1	0.4531	0.06
	80	0.5365	0.03	0.4705	0.03
	160	0.5458	0.09	0.4911	0.08
Controls					
	true control	0.4093		0.4907	
	fall injected	0.4427		0.5306	
	spring injected	0.4941		0.4293	
		Richness			
		1999		2000	
Season					
	fall	10.5	1.6	5.7	0.9
	spring	8.8	2.1	4.6	0.8
Method					
	broadcast	9.4	2.4	4.9	1.4
	injected	9.9	1.6	5.4	0.5
Rate					
	10	10.5	2.1	6.0	0.8
	20	8.8	2.8	5.0	0.8
	40	9.5	1.7	4.5	0.6
	80	9.8	1.0	5.3	1.0
	160	9.8	2.9	5.0	1.6
Controls					
	true control	13		6	
	fall injected	9		8	
	spring injected	10		6	

Table EIII-2: Mean community diversity and richness indices (+/-standard deviation) among treatment factors on the Crested Wheatgrass-Alfalfa pasture in 1999 and 2000

		Diversity			
Factor	**Level**	**1999**		**2000**	
		x	**sd**	**x**	**sd**
Season					
	fall	0.3577	0.07	0.1553	0.08
	spring	0.3058	0.07	0.1668	0.1
Method					
	broadcast	0.3385	0.09	0.1640	0.1
	injected	0.3251	0.06	0.1582	0.1
Rate					
	10	0.3540	0.08	0.2336	0.09
	20	0.3967	0.08	0.2370	0.08
	40	0.3396	0.04	0.1987	0.03
	80	0.2997	0.05	0.0732	0.04
	160	0.2690	0.05	0.0629	0.05
Controls					
	true control	0.4560		0.3201	
	fall injected	0.3168		0.2418	
	spring injected	0.3880		0.2387	
		Richness			
		1999		**2000**	
Season					
	fall	7.1	1.7	2.8	1.0
	spring	6.7	1.3	3.2	0.9
Method					
	broadcast	7.0	1.5	3.2	1.0
	injected	6.8	1.5	2.8	0.9
Rate					
	10	7.8	1.0	4.0	0.8
	20	8.0	1.4	2.8	1.0
	40	5.8	1.3	3.3	1.0
	80	7.0	1.4	2.8	1.0
	160	6.0	1.4	2.3	0.5
Controls					
	true control	6		6	
	fall injected	7		3	
	spring injected	8		2	

Table EIII-3: Mean community diversity and richness indices (+/-standard deviation) among treatment factors on the Fescue Grassland community in 1999 and 2000

		Diversity			
Factor	**Level**	**1999**		**2000**	
		x	**sd**	**x**	**sd**
Season					
	fall	0.6314	0.1671	0.6330	0.08
	spring	0.6518	0.1142	0.6255	0.08
Method					
	broadcast	0.6513	0.1422	0.6072	0.07
	injected	0.6818	0.6818	0.6513	0.09
Rate					
	10	0.5401	0.0700	0.5950	0.05
	20	0.5726	0.1097	0.5946	0.06
	40	0.6464	0.1423	0.6201	0.05
	80	0.6562	0.1598	0.5924	0.05
	160	0.7928	0.0963	0.7441	0.08
Controls					
	true control	0.6386		0.5907	
	fall injected	0.6326		0.6013	
	spring injected	0.5784		0.6129	
		Richness			
		1999		**2000**	
Season					
	fall	16.1	3.1	13.7	2.4
	spring	15.7	2.4	13.2	1.5
Method					
	broadcast	16.0	2.0	13.3	1.7
	injected	15.8	3.4	13.6	2.3
Rate					
	10	15.3	1.5	11.8	1.7
	20	14.0	1.8	12.8	2.1
	40	16.0	1.8	14.3	2.6
	80	16.5	3.1	14.0	1.4
	160	17.8	4.1	14.5	1.3
Controls					
	true control	17		14	
	fall injected	17		15	
	spring injected	17		14	

Table EIII-4: Mean community diversity and richness indices (+/-standard deviation) among treatment factors on the Mixed Prairie community in 1999 and 2000

		Diversity			
Factor	**Level**	**1999**		**2000**	
		x	**sd**	**x**	**sd**
Season					
	fall	0.9608	0.03	0.8065	0.09
	spring	0.9631	0.04	0.8279	0.06
Method					
	broadcast	0.9483	0.04	0.8114	0.09
	injected	0.9755	0.03	0.8230	0.05
Rate					
	10	0.9611	0.03	0.8594	0.02
	20	0.9443	0.04	0.8592	0.02
	40	0.9661	0.06	0.8064	0.07
	80	0.9855	0.01	0.7582	0.1
	160	0.9525	0.04	0.8027	0.01
Controls					
	true control	0.9327		0.8215	
	fall injected	0.9311		0.8828	
	spring injected	0.9434		0.8146	
		Richness			
		1999		**2000**	
Season					
	fall	16.8	1.2	13.2	2.2
	spring	17.8	2.1	13.8	2.7
Method					
	broadcast	17.1	1.0	13.3	2.6
	injected	17.5	2.4	13.7	2.4
Rate					
	10	18.3	2.2	14.5	1.0
	20	17.8	2.4	16.0	2.2
	40	17.5	1.3	12.3	2.6
	80	17.3	1.0	12.5	3.1
	160	15.8	1.5	12.3	0.5
Controls					
	true control	15		10	
	fall injected	14		13	
	spring injected	15		10	